Responding to National Needs

THE NATIONAL BUREAU OF STANDARDS BECOMES THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

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James F. Schooley

NIST

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NIST
National Institute of Standards and Technology
Technology Administration
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Responding to National Needs

The National Bureau of Standards Becomes the National Institute of Standards and Technology 1969–1993

James F. Schooley

November 2000

U.S. Department of Commerce
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Technology Administration
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National Institute of Standards and Technology
Raymond G. Kammer, Director

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FOREWORD

On March 3, 1901, Congress enacted the law that gave birth to the National Bureau of Standards (NBS), renamed the National Institute of Standards and Technology (NIST) in 1988. Although the bill defining NBS was only two pages long, the words carried much importance because the United States desperately needed a standards and measurement agency. To quote a committee report to the House of Representatives 10 months earlier: "It is therefore the unanimous opinion of your committee that no more essential aid could be given to manufacturing, commerce, the makers of scientific apparatus, the scientific work of the Government, of schools, colleges, and universities than by the establishment of the institution proposed in this bill." Today, these words adorn the entrance to the NIST headquarters in Gaithersburg, Maryland, and continue to inspire the staff.

Over the years NBS and NIST have made great contributions to these objectives and to the welfare of our country by distributing critically evaluated reference data and carefully certified reference materials and by developing reproducible measurement standards, including those of time, frequency, length, voltage and resistance that are now based on durable and reproducible quantized quantities. NIST scientists have also contributed to basic science in many ways, such as measuring the fundamental physical constants and showing the invalidity of the assumed parity symmetry for elementary particles. NIST continues to contribute to industry, computer science, health, medical science, safety, fire protection and other fields through its development of standards, quality assurance, and new technologies such as computer controlled manufacturing.

In the year 2001, NIST will be celebrating its Centennial, honoring and recognizing its contributions to the world of science and technology, American industry, and the economy over the last 100 years. The theme for this celebration is "NIST at 100: Foundations for Progress." The history of the Institute's first 50 years was covered by *Measures for Progress,* which was published in 1966 by the U.S. Department of Commerce. It captures the achievements through which NBS expertise fostered the technological changes in our country during a time of revolutionary advances in science and technology, driven in part by the development of quantum mechanics and two world wars. *Measures for Progress* was followed by the publication of *A Unique Institution*, a history of the Institute between the years of 1950-1969, years heralding the dawn of the Information Age.

This new volume, *Responding to National Needs,* covering the years 1969-1993, describes further scientific and technological advances and the evolution of NIST into an Institution that has also impacted and helped U.S. private industry and interests on a global basis. For example, the Advanced Technology Program has aided the development of innovative technologies that brought many new products and services to market. The Baldrige National Quality program has emphasized quality as a national priority necessary to compete in a global marketplace, and the Manufacturing Extension Partnership has helped many small U.S. manufacturers enhance their global competitiveness by providing information and assistance on manufacturing technologies. At the same time, NIST, through its own efforts and through Precision Measurements Grants, has continued to make fundamental contributions to science and engineering, such as improved atomic clocks, the discovery of the first anapole moment, laser cooling of ions and atoms, and pioneering research that led to the observation of a Bose-Einstein Condensate in 1995. This book records the rich recent history of NIST and illustrates its many contributions to knowledge, technology, and society.

Norman F. Ramsey
Harvard University

PREFACE

Responding to National Needs is a remarkably appropriate title for this volume on the history of an institution that was created by Congress for that very purpose. In a sense, every Federal agency is established to respond to needs perceived as being important to the Nation's well-being. In that respect, the National Institute of Standards and Technology has much in common with hundreds of other organizations. But perhaps more than any other agency, our mission has been fine-tuned with the addition of literally dozens of new assignments, all designed to help the United States solve some problem, to take advantage of some opportunity, and to improve our economic strength and societal well-being.

The evidence found in Federal statute books shows clearly that NIST has responded to National needs in a meaningful way over the past 100 years. But especially over the period covered in this volume, 1969-1993, the assignments by our country's lawmakers exploded. We gained or expanded responsibilities for work as varied as energy conservation and recycling, the metric system, fire safety, computer security, quality improvement, assistance to smaller manufacturers, advanced technology research and development funding and quality improvement in companies. In all, from 1969 to 1993, 79 separate pieces of law recognized NIST's capabilities and added to them.

The most significant of these literally changed the name of the institution from the venerable National Bureau of Standards to the National Institute of Standards and Technology. As this document notes, the change came because the Congress recognized an urgent need to help boost the competitiveness of U.S. industry. The change was not without tension and controversy, both within the institution and on Capitol Hill. I was intimately involved in discussions about the new assignments that accompanied the name change. There was as much debate at "the Bureau" as there was in Congress. Insiders worried about possible damage to our reputation for excellence in laboratory-based research, and about our ability to maintain our reputation for third-party independence. Those of us who supported the change took a chance. But we knew that NBS always had responded to national needs, and the Nation clearly needed the assistance of a Federal agency with a strong track record, close ties to industry, and a history of quality work.

That risk-taking has paid off handsomely. Today, the NIST Advanced Technology Program—though still politically controversial among some that question the government's role in supporting civilian technologies—has generated dozens of successes by co-funding high-risk technologies developed by industry. The Manufacturing Extension Partnership—now offering services in every state and Puerto Rico—has helped more than 80,000 smaller companies to be more productive and competitive. The Baldrige National Quality Program has proven so successful in promoting and recognizing quality improvement and performance excellence by manufacturers and service firms that NIST recently was assigned to help foster this approach among organizations in the education and health care communities.

There was no need to fear that these additional assignments would negatively impact the measurement and standards laboratories—the core of the agency. Our laboratories are as healthy as they ever have been. While a variety of overseas metrology laboratories have been subjected to substantial reductions and privatization, the NIST laboratories remain intact and extraordinarily productive. In 1997 and 1998, we added a Nobel Prize in Physics and a National Medal of Science to the cache of distinctions held by NIST researchers. Today we count 11 members of the National Academies of Science and Engineering among our active staff. During the time covered in this historical installment, we branched out into entirely new—and sorely needed areas of science and technology.

Responding to national needs is not easy. It certainly challenges the "comfort level" of an agency and its staff. As you read this volume, you will note the dozens of ways in which NBS and then NIST were called upon by the Nation—and how we delivered. I believe that is the ultimate test of an organization's usefulness. NIST has passed the test with flying colors.

Raymond G. Kammer
Director
National Institute of Standards and Technology

ACKNOWLEDGMENTS

Preparation of this history involved many people, probably more than I can remember. The willing cooperation they gave to the project was a continuing source of pleasure and strength for me as I strove to represent the multiple facets of NBS/NIST.

Karma A. Beal guided me to the prime sources of information on this institution and answered endless questions with speed, grace, and accuracy. Along with Ralph P. Hudson, she also reviewed the entire manuscript. I thank them both for their generous assistance with the history project.

Lisa A. Greenhouse produced an endless array of historical photographs from a variety of arcane locations, and she provided a consistently insightful judgment on their illustrative value. The text is much the richer for her enthusiastic participation. I am greatly in her debt.

Among the most valuable contributions to the history came from the many present and former NBS/NIST employees who reviewed various portions of the text for relevance and accuracy. They saved me from many errors—any that remain are mine. I am deeply grateful to the following people for their efforts: Ernest Ambler, Karma Beal, Brian Belanger, Norman B. Belecki, Lawrence H. Bennett, Lewis M. Branscomb, Jack H. Colwell, Bert M. Coursey, Gordon Day, Eugene Domalski, David Evans, Judson C. French, J. William Gadzuk, Jon Geist, Cary Gravatt, Daniel Gross, Gail Hixenbaugh, John D. Hoffman, Jeffrey Horlick, Emanuel Horowitz, Ralph P. Hudson, Marilyn Jacox, Donald R. Johnson, Ronald Johnson, Robert A. Kamper, Russell A. Kirsch, Ralph Klein, Samuel Kramer, Richard H. Kropschot, Lawrence M. Kushner, Walter Leight, David R. Lide, Jr., Frank Lovas, John W. Lyons, J. Franklin Mayo-Wells, Hans Oser, William R. Ott, H. Steffen Peiser, William D. Phillips, Shirley M. Radack, Roger A. Rensberger, Arthur W. Ruff, John J. Rush, Robert Schaffer, Johanna M.H. Levelt Sengers, John A. Simpson, Jack E. Snell, Wilbert E. Snyder, Barry N. Taylor, W. Reeves Tilley, Donald H. Tsai, John B. Wachtman, Jr., Robert S. Walleigh, James R. Wright, and Richard N. Wright. I apologize to those whose help I have forgotten to acknowledge.

Accurate preparation of the endpapers, the front matter, the index, and specialized information needed for the appendices was challenging. Diane Cunningham, Susan Makar, and Stella Hsu, Research Librarians; Lori Frederick, Chief of the Electronic Information and Publications Program; Carolyn J. Stull of the Visiting Committee Office; Janet B. Miller and Suzanne C. Evans of the Budget Office; Gail K. Ehrlich of the Program Office; and Jane Watterson, Boulder Research Librarian, all contributed cheerfully and quickly to requests for assistance.

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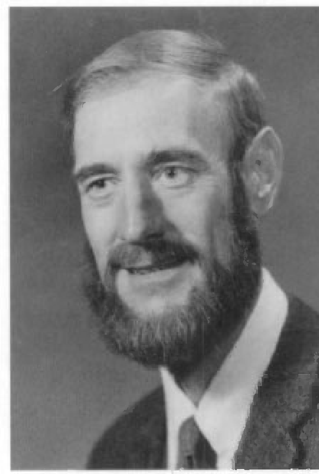
Thomas F. Lacko and Wanda L. Reed provided valuable service in maintaining a computer-based facility for my use throughout the life of this project.

The reader should note that, in many of the references quoted in the text, the units used by the authors were not those currently recommended as part of the International System of Units. In the interest of historical accuracy, the older units have been retained in the discussions of these projects.



I am grateful to Paul Vassallo and to Mary-Deirdre Coraggio of the NIST Office of Information Services for their leadership of the history project, and to Sandra L. Kelley and Sandra E. Norris for their cheerful and efficient secretarial services. Ms. Coraggio, in particular, speeded the progress of the project by assigning full responsibility for indexing the text to the SAIC Corporation. John V. Norris of SAIC ably assisted with reviews of the text in proof.

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Chief, Temperature and Pressure
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Gaithersburg, Maryland
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CHAPTER ONE

A UNIQUE INSTITUTION

CHANGE COMES TO A MIDDLE-AGED AGENCY

In 1968 the National Bureau of Standards was about to lose a Director who nearly had become an institution himself. With that loss the nature of the agency would begin to change, although no one could foresee the manner of change, so subtle were its beginnings.

Allen Astin, leader of the Bureau for a decade and a half, was a scientist of the old school, not different in material ways from his four predecessors as Director: his most precious possessions were his scientific and personal integrity; his devotion to the institution was absolute; the efforts of his hours, days and years hewed to the goal of providing useful purpose for his staff and obtaining for them the best working environment he could provide.

In the exercise of his duties Astin had asked no quarter from his superiors. And in truth, he had received but little. A more desired commodity, however, he had been granted in abundance by all who crossed his path—respect for his ability and for his unflinching honesty.

Our story begins with Astin's last year as Director. Most of his work is chronicled in the volume that serves as companion to this one.[1] As we assess the institution that he left behind, however, we shall see that its uniqueness in 1968 derived in no small measure from the careful and devoted nurture of Allen Astin and his predecessors.

The end of Astin's career as Director came as the Nation's funding of scientific research and development had ceased to grow at a double-digit rate. In fact, by every mark, funding of basic science and both civilian and military research and development reached a standstill during this period.[2] The events that had led to the flagging of support for America's scientific establishment were linked tightly to the origins of impending change for the National Bureau of Standards.

Gradually, during the decades of the 1950s and 1960s, America began to lose the world dominance won at so great a price in World War II. The post-war boom in the U.S. economy had fueled a corresponding jump in its standard of living, with America leading a world-wide increase in trade. But the party became noticeably quieter as the strain of war—first in Korea, then in Vietnam—coupled with a multitude of problems within the Nation's borders to unsettle the lives of ordinary Americans. Growing

[1] Elio Passaglia with Karma A. Beal, *A UNIQUE INSTITUTION: The National Bureau of Standards, 1950-1969* (Washington, DC: U.S. Government Printing Office, 1999).

[2] Deborah Shapley and Rustum Roy, *Lost At The Frontier: U.S. Science and Technology Policy Adrift*, (Philadelphia: ISI Press, 1985), pp. 4-5, Figs. 1A, 1B, 1C.

inflation and interest rates, anti-trust actions, worry over pollution and loss of natural resources, all these factors created doubt in the minds of U.S. citizens that more and more science would provide the quality of life that they wanted for themselves and their children.[3]

As a result of environmental and health concerns, Americans demanded better protection from the poisonous side effects of U.S. industrial production. There began a series of ecologically based actions by the Congress—the Land and Water Act of 1964, the Water Pollution Act and the Clean Air Act of 1965, the Clean Water Restoration Act of 1966, and later the Environmental Protection Act, the Toxic Substances Control Act, the Occupational Health and Safety Act, and amendments to the Clean Air Act. This legislation would engender compliance costs estimated at $63 billion for the year 1976 and $100 billion by 1979.[4]

Not until 1980 would the balance of payments shift dramatically to the negative for the United States, but worrisome signs abounded in 1968. As Astin prepared to retire, many members of Congress contemplated ways in which they could help American industry maintain leadership in the world economy. The solution seemed to lie in helping U.S. industry to apply modern technology more effectively. NBS was known—to the relatively few Congressmen who knew it at all—as a center of technical competence. It was the Nation's "problem-solver" as well as the final authority on measurement standards. If NBS were to exert more leadership in applying new technology, perhaps it could play a larger part in keeping America's production strong . . .

But we get ahead of ourselves. Let us take the time to examine the National Bureau of Standards to see why, indeed, it should be known as a unique institution.

Origin of the National Bureau of Standards

The Federal agency that is now called the National Institute of Standards and Technology was created as the National Bureau of Standards by the 56th Congress of the United States. The chartering legislation, reported in "The Statutes at Large of the United States of America," Volume XXXI, Chapter 872, page 1449, was approved on March 3, 1901, during the second session of the 56th Congress. The shorthand reference to the chartering act is 31 Stat. 1449 (the act is now known as Public Law 56-177); it occupies less than two pages of text.

The ten relatively short sections of Public Law 56-177[5] do not appear remarkable from the distance of ninety-odd years, but they outline in succinct form a strong, laboratory-based agency with well-developed functions and a small but highly technical staff.

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[3] Paul Johnson, Modern Times: *The World From the Twenties to the Nineties, Revised Edition,* (New York: Harper Perennial, 1991), Ch. 19.

[4] Robert DeFina, *Public and Private Expenditures for Federal Regulation of Business* (St. Louis: Washington University, 1977). Murray L. Weidenbaum, *Governmental Power and Business* (Stanford, 1980).

[5] Reproduced in Appendix A.

The birth of the National Bureau of Standards followed a surprisingly long gestation. However, by virtue of the comprehensive powers given to it by its chartering legislation, the infant agency was able to develop quickly into an effective organization. The only ingredient that Congress, on its own, could not supply was spirited and forward-looking leadership. Fortunately, that ingredient quickly materialized in the person of Samuel W. Stratton, whose contributions will be discussed shortly.

Constitutional Authority

The founding fathers provided to Congress all the authority it needed for the creation of a National Bureau of Standards more than a century before its actual founding. This authority is explicit in the U.S. Constitution. There can be no doubt that the men who wrote the Constitution recognized the importance of uniform standards of measurement to ensure an equitable and orderly commerce for the new country, for they juxtaposed that authority with the basic monetary authority. The text of Article 1, Section 8 of the Constitution reads, in part: "The Congress shall have Power . . . To coin Money, regulate the Value thereof, and of foreign Coin, and fix the Standard of Weights and Measures . . . "

Following the organization of the major executive, legislative, and judicial branches of the new government, the Congress quickly acted to regulate the coinage of the new nation. A United States Mint was established by congressional action on April 2, 1792, a scant three years after the inauguration of George Washington as the first President. Curiously, however, the Congress was hesitant to act on its co-equal authority with respect to weights and measures, despite the clear and growing need for uniformity in manufacture and commerce and despite specific requests from President Washington.

"Customary Standards"

The need for Congress to "fix the standard" for weights and measures arose in substantial part from the complex state of industrial and commercial measurements prior to the 19th century. Early citizens of the United States, harking back to origins throughout Europe and, to some extent, in lands beyond, made use of a staggering variety of measured quantities and their scales. The "inch," the "hand," the "foot," the "yard," the "fathom," the "chain," and the "rod" were just a few of the linear measures in use during that time. Area was measured in terms of the "perch," the "square inch," the "square meter," the "acre," and the "hectare," among others. Volumetric measures included the "fluid ounce," the "gallon," the "peck," the "dry quart," the "bushel," the "cord," and the "firkin." Weight units were as diverse as the "grain," the "pound," the "troy ounce," the "ton," the "short ton," and the "long ton." The relationships among the various industrial and commercial measures were tenuous at best. Even merchants with the most honest intentions could not deliver uniform amounts of their goods to their customers for want of adequate measuring devices. The occasional instance of a vendor's greed, added to the difficulty of accurate measurement, made shopping a punishing exercise indeed for the early consumer!

A Baltimore city inspector tested a grocery store scale for accuracy, about 1920. Photo appears courtesy of the Maryland Department of Agriculture (Weights and Measures Section).

The variety of coins that were intimate parts of the lives of America's citizens at the time it became a nation was not nearly so large as the panoply of weights and measures. Why did the Congress quickly choose to set up a system of coinage and a mint to regularize the monetary system, yet hesitate to select or concoct a standard set of commercial and manufacturing measures? From a distance of nearly two centuries, this inconsistency is puzzling.

As the decades passed, various Congresses, urged on by a citizenry suffering under the chaotic state of U.S. measurement standards, made only halting efforts in the direction of establishing a National Bureau of Standards.[6] The Congresses received periodic requests for action on standards from representatives of U.S. science and industry, reinforced by louder and louder outcries from hard-pressed citizens who clamored for uniformity in commercial weights and measures. Technical workers needed measurement standards in order to produce useful goods; ordinary citizens desperately wanted fair and uniform measurements from vendors of foods and other goods whose scales either were inaccurate as a result of poor construction or had been adjusted so as to maximize profits. Surely, something could be done for these people . . .

[6] John Perry, *The Story of Standards* (New York: Funk & Wagnalls Company, 1955) Chapters 1-6.

In 1816 President James Madison called for the adoption of a decimal system of measurement that had been proposed by Thomas Jefferson when the latter was Secretary of State. Considerable congressional discussion followed this suggestion, including an extensive report by then-Secretary of State John Quincy Adams. Nothing came of these efforts directly; it may be that the dominance of English roots among America's leaders kept them from embracing an idea that arose in France, or a lack of agreement over certain of the metric definitions. Nevertheless, the discussions became part of the legislative dossier that led eventually to the creation of a national standards bureau.

The Office of Weights and Measures

A palpable step towards creation of national weights and measures for America occurred in June of 1836 when a Joint Resolution of Congress (5 Stat. 133) was passed directing the Secretary of the Treasury to "... cause a complete set of all the weights and measures adopted as standards ... to be delivered to the Governor of each State in the Union ...." The astute reader will notice immediately the incongruity of the phrase in the resolution "... weights and measures adopted as standards ... " in comparison with the constitutional authority to "fix the standard of weights and measures." One is impelled to ask, why did not the Congress adopt standards as the Constitution gave them the authority to do? Who *did* adopt measurement standards? What standards were available to be adopted? The answers to these questions will lead us to the creation of the National Bureau of Standards.

The situation behind the curious phrase in the 1836 resolution relates particularly to a man named Ferdinand Hassler. We need to know something about Hassler—and Charles Peirce, another metrologist who carried forward Hassler's principles—if we are to understand the growth of the standards movement in America. The following material is based upon Cochrane's well-written and informative account in "Measures for Progress."[7]

Ferdinand Rudolph Hassler

Ferdinand Hassler was the first Superintendent of the Coast Survey and the first Superintendent of Weights and Measures. He has been described as "the first scientist of rank in the employ of the Federal Government."[8] He certainly provided the U.S. Congress with first-hand knowledge of both the inspirations and the exasperations involved in dealing with a determined scientific mind.

Born to a well-to-do family in northern Switzerland in 1770, Hassler entered the University of Berne at age 16. His inquisitive and agile mind was captured by the subjects of mathematics, astronomy, and geodetics. With a professor from the school, Hassler began a lifelong pursuit of practical geodetics. While mapping the countryside

[7] Rexmond C. Cochrane, *Measures For Progress* Natl. Bur. Std. (U.S.) Miscellaneous Publication 275 (Washington DC: U.S. Department of Commerce, 1966), Ch. I and Appendices A, B, and C. Hereafter, *Measures For Progress* will often be abbreviated as MFP.

[8] MFP, p. 525.

Ferdinand R. Hassler as a young man in the 1790s. Born and educated in Switzerland, he became America's first great metrologist. Photo appears courtesy of the American Philosophical Society.

near the university, the two men found it difficult to use the measuring instruments at hand. The devices were imprecise and there were few measurement standards. Has sler's future life as a metrologist very probably was formed by this experience.

Hassler decided to leave Switzerland because of the widespread turmoil that accompanied the French Revolution. In 1804 he conspired with a chance acquaintance to found a Swiss colony in the United States, entrusting the stranger with most of his fortune to precede him and buy land for this purpose. Meanwhile, Hassler assembled an entourage consisting of his wife, four children, considerable baggage, and some 120 craftsmen and their families; he then chartered a small ship to carry his nascent colony to Philadelphia.

Hassler's colonial venture disintegrated quickly when his erstwhile partner confessed to having gambled away the money that Hassler had entrusted to his care!

Undaunted, Hassler contacted the Secretary of the Treasury, Albert Gallatin, a fellow Swiss by birth; through Gallatin, Hassler met President Thomas Jefferson. Perhaps they shared a common interest in metrology. In any case, when the 9th U.S. Congress appropriated funds in 1807 for a coastal survey of the United States, Hassler's plan for the survey was judged most satisfactory. Hassler advocated the use of astronomy to locate geographic positions at key coastal points, to establish networks of precise triangulation connecting them, and to create topographical surveys of coastal regions including coastal waters.

Delighted with his new position, Hassler soon traveled to London to oversee the production of suitable instruments for the task. He stayed in England and France for four years, consulting with geodesists on the techniques of measurement and designing astronomical instruments for purposes well beyond his statutory requirements.

In 1815 Hassler returned to America. He already had overspent his budget by about 10 percent, and only then was he about to begin working on the survey. The next year, hard at work training a cadre of assistants, Hassler was given the title of Superintendent of the Survey of the Coast, a salary, and permission to start the project.

Hassler's progress was much too slow to satisfy Congress. In 1818 the 15th Congress took the project away from him and gave it to the military in the hope of obtaining quicker results. While it is true that Hassler had made no maps of the coast to show Congress by that time, historian Elliott Roberts noted in 1957 that the survey was then still in progress with no end in sight.[9]

For 10 years after losing his commission, Hassler tried more mundane occupations—farming, teaching, and writing textbooks. His temperament, erratic at best, prevented economic success.

In 1829 Hassler took a position as gager (a measurement specialist) at the New York Custom House. American measurement standards were still in poor condition—in fact, Congress was of the opinion that the backward state of U.S. standards was hampering the Nation's progress in international trade. Fortune smiled upon Hassler then, for Congress authorized a comparison of the standards used in U.S. customhouses and Hassler was selected by President Andrew Jackson to head the project.

Characteristically, Hassler immediately planned a bigger project than had been contemplated by Congress. He not only produced overwhelming evidence of serious deficiencies in American measurement standards—they were faulty in their definition and construction, and inconsistent in their results—but he also undertook to adopt, produce, and distribute better standards.

With the approval of Treasury Secretary Samuel Ingham, Hassler selected units of measure and prepared new devices to realize the units. In 1832 the Treasury Department adopted Hassler's suggestions for length, mass, and capacity; it was these "adopted standards" to which Congress referred in its resolution of 1836.

Historians regard the 1836 Resolution as the instrument of creation of the Office of Weights and Measures within the Coast Survey of the Treasury Department, with Ferdinand Hassler as its first Superintendent. This Office, 65 years later, would be subsumed into the National Bureau of Standards.

Hassler was in certain respects a prototypical metrologist. He had set his own goals for the Coast Survey—to see first to the construction of instruments of the highest quality, never mind the time or cost. He endured the loss of his post that resulted from his choices; when his project was passed to the military because of his apparent lack of progress, he continued doggedly along his chosen path until he exhausted his personal fortune. It is entirely suitable that his abilities should have been recognized in 1922 by Samuel Stratton, first Director of the National Bureau of Standards, in the words "I

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[9] Elliott B. Roberts, "United States Coast and Geodetic Survey, 1807-1957," *Ann. Rep. Smithsonian Institution*, 1957, p. 222.

doubt if there were more than half a dozen people in the world at that time who possessed the scientific knowledge and the deftness of the artisan necessary to undertake his work."

Charles Sanders Peirce

Charles Peirce, born near the end of Hassler's tumultuous life, is remembered as an outstanding scientist and philosopher, with a strong bent for metrology. He spent 20 years with the U.S. Coast and Geodetic Survey, much of it in the study of weights and measures. Long before the advent of laser metrology, Peirce evaluated the meter in terms of a wavelength of light, and he spent considerable effort in the determination of relative values of gravity both in the United States and in Europe. In the process of these and other studies, Peirce advanced noticeably the scientific approach to measurement problems. [10]

During Peirce's brief tenure as head of the Office of Weights and Measures, a subsidiary of the Coast and Geodetic Survey, it happened that a Joint Commission of Congress was appointed under the chairmanship of Senator William B. Allison to "consider the present organization of the Signal Service, Geological Survey, Coast and Geodetic Survey, and the Hydrographic Office of the Navy Department." Asked to testify before the Allison Commission in January 1985, Peirce called attention to the inadequacy of then-current standards of weights and measures. He followed by noting a resolution of the American Metrological Society that called for the strengthening of the Office of Weights and Measures—in fact, the resolution sought the creation of a "national bureau of weights, measures, and physical units."

Like the work of Hassler a half-century earlier, Peirce's efforts became part of the congressional dossier that culminated in the creation of the National Bureau of Standards.

The Metric System

As the United States of America came into being at the end of the 18th century, the so-called "metric system" was initiated in France.[11] In this system, all quantitative measures are based upon the "metre" (herein we use the American spelling, "meter") and the "gramme" (herein spelled "gram").[12] The meter was to be the standard of length, defined by a committee of the French Academy of Sciences as one ten-millionth part of the distance from the equator to the North Pole.[13] The gram was to be

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[10] Victor F. Lenzen, "The contributions of Charles S. Peirce to metrology," *Proc. Amer. Philosophical Soc.* **109**, pp 29-46 (1965).

[11] Chester H. Page and Paul Vigoureux, editors, *The International Bureau of Weights and Measures 1875-1975*, Natl. Bur. Stand. (U.S.) Special Publication 420, May 1975.

[12] Barry N. Taylor, The International System of Units (SI), NIST (U.S.) Special Publication 330, August 1991, Foreword.

[13] It is recorded (see MFP, Appendix B) that members of the French Academy actually participated in measurements evaluating the meter along the meridian that passes through Barcelona, Paris, and Dunkirk (approximately 2.4 degrees east of the Greenwich meridian), traveling through hilly terrain to do so.

the standard of mass,[14] defined as the mass of one cubic centimeter of pure water at its maximum density (the maximum occurs near 4 °C).

The metric system had two very attractive features. First, it was defined in terms of natural units—in principle, any competent technician could duplicate the meter and the gram without recourse to artifacts. Second, the system was defined in a decimal fashion—multiples and sub-multiples of the units were derived by use of the factor 10. A simple system, indeed, compared to the complicated alternatives!

The principle of a decimal system of weights and measures embodied in the French metric system was put in place in Switzerland during the first half of the 19th century. Twelve Swiss cantons entered an agreement to employ a set of decimal units for certain of their measurements.[15] It was only a small step, but one that accurately forecast the direction for future international standards.

Although adoption of the metric system for measurement standards in the U.S. was recommended by—among others—President Jefferson, only in 1866 did the Congress authorize the use of metric standards. Even then, the system was not made compulsory—merely lawful.

By 1869 the metric system was considered ready for use in international technology and trade. The system already was specified by law in France, Holland, Belgium, Luxembourg, Spain, Colombia, and Mexico, and was recognized in England, Germany, and the United States. In 1869 the government of France invited many countries to send delegates to Paris to attend an "International Commission for the Meter." A highlight of the meeting would be discussion of the designation of the French meter and kilogram, preserved in the Archives of Paris, as references for international measurement standards. As matters proceeded, meetings of the Commission were delayed until 1872 because of political unrest in France.[16]

On March 1, 1875, the French government convoked the Diplomatic Conference on the Meter. Its aims were substantially those of the earlier Commission. The conference was attended by representatives of 20 nations, including Elihu Benjamin Washburne—"Envoy Extraordinary and Minister Plenipotentiary"—and Joseph Henry—first Secretary of the Smithsonian Institution—representing U.S. President Ulysses S. Grant. By May 20, the conferees had created an impressive organization for international standards of measurement. The organization included the following entities:

[14] The careful reader will note that the words "mass" and "weight" have been and often still are used interchangeably, as if they represent identical quantities. Strictly speaking, they do not; weight is actually a force, equal to mass times the acceleration due to gravity. The distinction is often overlooked because most masses are evaluated by weighing and because geographical variations in gravitational acceleration are small. Later in this book (Sec. 2.8.5, Force Testing on a Large Scale) we provide more details on the difference between mass and weight.

[15] W. Schwitz, *Formation and Development of the Swiss Federal Measurement System,* translation by H. Steffen Peiser.

[16] Actually, the word "unrest" hardly does justice to that period of time in France. The Franco-Prussian War took place in 1870. The same year saw the end of the reign of Louis Napoleon and the formation of the Third Republic of France. Unrest, indeed!

- An International Committee for Weights and Measures (known today by the acronym CIPM, corresponding to its title in French), intended to oversee the production of prototype standards.
- An International Bureau of Weights and Measures (BIPM), an administrative organization and a building where the standards would be prepared and where the administrative offices would be housed.
- Periodic General Conferences on Weights and Measures (CGPM), during which the signatory nations could adopt suitable standards for international reference.[17]

The United States was one of 17 countries that signed the "Convention du Mètre" (*Convention of the Meter,* the oldest treaty of which the United States is still a signatory). Despite its agreement to recognize the 1875 Convention, and despite the growing use of metric measurements throughout the world, the U.S. Congress never enacted legislation to adopt the metric system as the compulsory national standard for weights and measures in America.[18]

We shall return again and again to discussions of the International Bureau of Weights and Measures, because its history and that of NBS were tightly intertwined.

In later sections we shall also note a rebirth of congressional interest in mandating the metric system of measurement for everyday use in the United States. However, this issue has lost much of its urgency with the passage of time, inasmuch as all the units of the so-called "customary U.S." or "English" measures have long since been evaluated in terms of metric equivalents. Individuals or companies that need to use the metric system in manufacturing or in sales literature can readily make the transition—though often at the cost of duplication of equipment and inventories.

At Last, a National Bureau of Standards

As the 20th century opened, the House Committee on Coinage, Weights, and Measures received a letter from Lyman Gage, Secretary of the Treasury, who suggested the creation of a national standardizing bureau. This letter was the product of a meeting of the minds of Secretary Gage and one Samuel W. Stratton, a professor at the

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[17] In 1927, the CIPM began to establish Consultative Committees to assist it in preparing new statements on standards. These committees were composed of scientists expert in one of the metrological areas. Eventually, most measurement units (for time, mass, length, temperature, electrical quantities, etc.) came under the care of a consultative committee.

[18] It is perhaps worth noting that the metric system of measurements *was* prescribed for use by the American Expeditionary Forces during World War I. A U.S. Army General Order dated January 2, 1918 specified that the metric system was to be used ". . . for all firing data for artillery and machine guns, in the preparation of operation orders, and in map construction." Metric literature that was distributed to both Army and Navy technical personnel included wall charts, sets of equivalents between metric and customary units, and National Bureau of Standards Miscellaneous Publication No. 21 "Metric Manual for Soldiers—The Soldier's Manual of the System—An International Decimal System of Weights and Measures, adopted as the legal standard by France and 33 other nations and in world-wide use." Reference to NBS MP No. 21 can be found in *War Work of the Bureau of Standards,* Natl. Bur. Stand. Miscellaneous Publication 46, 1921, pp. 220-221.

University of Chicago. Stratton was convinced that the time for creation of a national bureau of standards had arrived. He had responded to a lesser offer from Gage—to appoint him chief of the Office of Weights and Measures—with a suggestion for a grander goal.

Gage's letter to the House committee, written with the direct assistance of Prof. Stratton, was only the latest in a long series of requests for congressional action on national standards. But this time, the spark ignited a flame. Testimony from U.S. technical leaders, encouraged to speak before the Committee, offered enthusiastic support for the idea. Members of the Committee were disposed to offer HR 1452, "National Standardizing Bureau," to the House on May 14, 1900. The Act worked its way through the 56th Congress in accordance with the usual Congressional practice.

On March 3, 1901, the legislation now known as Public Law 56-177, written by the Senate and the House of Representatives of the United States of America in Congress assembled, was approved. It established the National Bureau of Standards. The act decreed that the Office of Standard Weights and Measures should thereafter be known as the National Bureau of Standards. However, the provisions of the act made it clear that "National Bureau of Standards" was not simply a new name for an old office. A wholly new agency was being created—one with considerably more responsibilities than its forerunner. In Appendix A we provide excerpts from all of the legislation affecting NBS, beginning with the U.S. Constitution.

A Word About Standards

It might be helpful at this point to consider for a moment the question "What are standards?" The question is not an idle one. Over the years, millions of dollars have been appropriated by one Congress or another for work at NBS that various members of Congress have criticized as lying beyond the scope of Public Law 56-177.

Webster's New International Dictionary, 2nd Edition, defines "standard" as "That which is set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality, esp., the original specimen weight or measure sanctioned by government, as the standard pound, gallon, yard, meter, or the like."[19] From that definition, one can readily construct a menu of standards that includes all the physical metrics—units such as those of length, mass, time, frequency, temperature, pressure, electrical resistance, electrical current, voltage, electrical capacitance, electrical impedance, radiant flux, hardness, and a raft of derivative measures; and metrics for chemistry, biology, radioactivity, sound, color, and other measurement-intensive fields. But what about standards for concrete fabrication? For computer security? For flammability of fabrics? For the safety of toys or tools? For the audibility of voice transmission? For tire wear? For police equipment? For home insulation? For earthquake-resistant buildings and bridges? Are these activities consistent with the instructions of Public Law 56-177?

[19] Walter G. Leight kindly points out that use of a single word—"standard," in the United States—both for scientific measurement methods and for guides to effective technical practices is not the case everywhere. In many countries, different words are used to refer to physical standards and to documentary guidelines.

Questions regarding the reasonable extension of the mandate contained in its Organic Act to new fields of derivative and applied standards of measurement surfaced on a regular basis after the Bureau was established in 1901. Sometimes a particular question has been avoided—by the Congress or by NBS management—and sometimes faced squarely (usually by modification of the Organic Act to include the contemplated project).

We shall have more to say later about arguments on the suitability of particular projects for the NBS mission, because such debates often help define the nature of the agency.[20] In proposing these projects, however, refining the mission of the Bureau was not ordinarily the intent of the petitioners for unusual work by the NBS staff. Instead, these people simply had problems to solve—and people with problems to solve tend to seek advice from other people whom they regard as experts.

It is to the credit of its leadership that, whatever its mandate, the Bureau has consistently been fortunate enough to house world experts on an amazing variety of technical subjects. The ability of a relatively anonymous government agency to attract and hold a distinguished staff in the face of continuing restrictions on hiring, salaries, and operating funds is itself remarkable. By creating a strong sense of shared mission to function as the Nation's measurement and data experts, the Bureau management has made it routine.

Responsibilities of the Newborn NBS

At its beginning, the National Bureau of Standards—"NBS" as it quickly became known throughout the metrological world—was only a tiny entity, hardly a match to its grand charter.

Public Law 56-177 decreed that the Office of Standard Weights and Measures should thenceforth be known as the National Bureau of Standards. The law designated a substantial list of functions for the new agency. They included the following:

- Custody of the standards.
- Comparison of standards used in science, engineering, manufacturing, commerce, and educational institutions.
- Construction of needed standards.
- Testing and calibration of measurement apparatus.
- Solution of standards-related problems.
- Determination of physical constants.
- Determination of properties of materials needed for science or industry, whenever such information might not be readily available from other sources.

The agency was directed to serve the standards needs of a great many communities: government at the national, state, and municipal levels; scientific societies; educational

[20] See Appendix A.

institutions; and corporations or individuals in the United States who were engaged in pursuits requiring the use of standards or standard measuring instruments. Its mandate was sufficiently broad as to permit nearly any activity in science or technology.

To accomplish so many tasks the act provided only a minimal work force—a director, a physicist, a chemist, an engineer, five technical assistants, and four nontechnical staff. The total salary cost was not to exceed $27,140 per year. Approximately $135,000 was appropriated toward the siting, construction, and equipping of a new laboratory building.

This was indeed a modest investment by a frugal Congress—but who could have foreseen the demands that would so soon be placed on the new Bureau by a nation that was rapidly becoming an industrial giant? It was a modest beginning, but it was a beginning nonetheless.

As we examine the work done within the National Bureau of Standards we shall see how the new agency not only fulfilled the responsibilities of the Office of Weights and Measures but also performed many vital tasks that provided the scientific basis for measurements and standards in industry and commerce. In addition to maintaining custody[21] of the standards, it was to offer a calibration service—free to governmental customers, at cost for others—and to harmonize the standards as used in the many technical aspects of U.S. life—for science, engineering, manufacturing, commerce, and education. Furthermore, the Bureau was required to "construct needed standards," a statement that is subject to differing interpretations but which literally directs the agency to respond to needs for measurement tools as expressed by its multi-faceted constituency. In time, these needs would include items as varied as radioactive standards, standard paint samples, a standard for iron in spinach, and standards for computer security.

Two entirely new directions, not formerly given to any agency, were the authority for "solution of standards-related problems" and "determination of physical constants and properties of materials such as might be needed by science or industry." Some members of Congress must have seen that they were thus mandating a vigorous laboratory enterprise, one that perforce must be staffed by first-rate scientists and engineers.

Similarly, the constituency of the new bureau was specified in the broadest of terms, as we have noted.

After failing to act on its constitutional prerogative for a hundred years, the Congress compensated for its procrastination by endowing the new National Bureau of Standards with all the authority it might ever need to serve the standards requirements of the United States. To help it maintain a suitable level of fiscal support for its new

[21] The word "custody," suggesting as it does the physical possession of an object, applied very well to the first standards maintained by the Bureau—standards such as a platinum-iridium-alloy meter bar and a platinum-iridium-alloy kilogram mass. In fact, these standards *did* reside in safekeeping at NBS. However, the word seems inappropriate when applied to the many modern standards that do not exist as artifacts at all. The position of the Bureau with respect to more recent standards such as length, defined in terms of a wavelength of light, or temperature, defined in terms of phase transitions in pure substances, seems better described by a word such as "responsibility." In this volume, we generally use the term "custody" only where an artifact standard is under discussion.

creation, Congress provided for oversight of the new bureau. This oversight was embodied in a "visiting committee," composed of five nongovernmental standards leaders appointed by the Secretary of the Treasury; the committee would visit the NBS annually and report to the Secretary on the efficacy of its work and the condition of its equipment.

Public Law 56-177, usually known as the "enabling legislation" of NBS but occasionally described in congressional jargon as its "Organic Act," was modified substantially in 1950, in 1968, and again in 1988,[22] but its foundation—the dual responsibilities for the Nation's standards and for resolving standards-related national problems—has remained in force throughout the agency's existence.

One feature *not* placed in the Organic Act of the NBS by the 56th Congress is any explicit reference to international standards of measurement. The absence of any such reference seems surprising from a modern perspective, particularly in view of the great importance to present-day science and industry of international standardization. When this history was written, all scientific and industrial measurements were validated in terms of international scales that were promulgated by the International Committee of Weights and Measures.

Why did the legislation establishing NBS not include a statement directing its staff to correspond with the BIPM, as the International Bureau of Weights and Measures is commonly known, the better to facilitate U.S. participation in world trade? Perhaps because the BIPM and its sister organizations were unknown to most members of Congress! Congress could not anticipate that the entities created by the Metric convention in 1875 would flourish with the years even as the National Bureau of Standards has done. In any case, this oversight has long since been rectified in practice; the newborn NBS soon found it necessary to participate in all areas of international standards work. Indeed, NBS has become a world leader in the development of international measurement standards.

HISTORIES OF NBS

The story of the growth of NBS, during its first 60-odd years, into a world-respected standards authority and a formidable scientific and engineering laboratory—literally a unique institution—is an important and fascinating one. However, it is not a story that we shall recount in detail here, because the interested reader can readily learn it from existing books.

In several histories, the reader can trace the transition in American commercial life that has resulted from the efforts of the Bureau. From the missing, inadequate, or dishonest weights that characterized the U.S. marketplace before the founding of the Bureau, to the economic ruin that occasionally accompanied a lack of standards in fire safety, transportation, and manufacturing, to the flowering of engineering standards during and after two world wars, the role that NBS played at the forefront of progress in measurement and standards for nearly seven decades has been documented by several authors.

[22] See Appendix A.

We mention here seven histories. To facilitate review by the interested reader, we list chapter titles and appendices for each book in Appendix B.

The careful reader will note that the titles of the first two histories refer to NBS not as "the National Bureau of Standards," but simply as "the Bureau of Standards"; these references do not indicate carelessness on the part of the authors, but rather a curious historical fact: in 1903, when the agency was transferred from the Treasury Department to the new Department of Commerce and Labor, the word "National" was eliminated from its title by George B. Cortelyou, the new secretary of Commerce and Labor. For about 30 years, the agency was known officially as the "Bureau of Standards." Through the efforts of Lyman J. Briggs, the agency's third director, the change was reversed.[23]

1. ***War Work of the Bureau of Standards,*** by an anonymous author, *Bureau of Standards Miscellaneous Publication 46,* U.S. Government Printing Office, 1921, 299 pp. This book contains fairly detailed discussions of some fifty groups of projects undertaken by Bureau staff members during WW I.

"Miscellaneous Publication 46" is particularly interesting because of its absolute anonymity. It contains virtually no names of persons. Not only are the descriptions of individual projects bereft of any reference to the staff members who accomplished them, but the monograph itself has no author—not even a reference that would identify where in the Bureau it was written. The apparent intention of this anonymity—not an uncommon trait during this time in the history of American government—was to avoid any appearance of immodesty on the part of the agency staff. Instead, each staff member was expected to take pride in all the work of the agency. Certainly, the attitude of belonging to a highly effective team has permeated NBS during most of its existence.

A glance at the NBS technical literature indicates that the names of scientific authors were listed under the titles of their scientific papers from the earliest days of the Bureau, but that summary accounts written by or for administrators generally were anonymous at least until the end of World War II.[24,25]

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[23] Cochrane, *Measures for Progress* p. 47.

[24] Churchill Eisenhart once mentioned an incident that occurred during the time when he was chief of the Statistical Engineering Section. Another Section staff member, Mary Natrella, prepared an extensive discussion of experimental statistics for the Office of Ordnance Research which was promulgated as U.S. Army Ordnance Pamphlets ORDP 20-110, ORDP 20-111, ORDP 20-112, ORDP 20-113, and ORDP 20-114. It was necessary for Eisenhart to negotiate with the sponsor the right to identify Ms. Natrella as the author, inasmuch as it was not the Army's policy to identify authorship of such documents. Later, the series was reprinted in book form under the title *Experimental Statistics* (NBS Handbook 91, 1963). Recollection of W. Reeves Tilley, former chief of the Technical Reports Section.

[25] The tendency to modesty among the staff of the NBS reminds this writer of a statement he once heard in the NBS Heat Division from William R. Bigge, a physicist who operated a six-dial potentiometer at—and occasionally beyond—its uncertainty limit. Asked how he had mastered the arcane use of the device, Bigge shrugged, "Any high-school graduate could run this thing as well as I do—after, maybe, twenty years of practice."

Another interesting feature of this history is a statement in the Introduction revealing that "... practically all the time and energy of the Bureau's personnel were devoted to military problems during the period of hostilities ..."

2. ***The Bureau of Standards: Its History, Activities, and Organization,*** by Gustavus A. Weber, Johns Hopkins Press, 1925, 299 pp., is a concise, matter-of-fact summary of the NBS as it appeared in the period following the First World War. It was written under the auspices of the Institute for Government Research, Washington DC, as one of a series of "Service Monographs." As of 1925, there were 36 titles in this series. In the course of describing the work of the Bureau, Weber provides details of various acts of Congress in which the Bureau was given new projects to supplement—either temporarily or permanently—its original mandate. These include such topics as flame standards (35 Stat. 904, March 4, 1909), accuracy in coin weights (36 Stat. 1354, March 4, 1911), and accuracy of scales used in coal mines (43 Stat. 205, May 28, 1924; 43 Stat. 364, June 30, 1926).

As was the case in Miscellaneous Publication 46, Weber allows the NBS staff to toil in virtually complete anonymity.

3. ***NBS War Research—The National Bureau of Standards in World War II,*** by Lyman J. Briggs (Director Emeritus), U.S. Government Printing Office, September 1949, 188 pp. In the Foreword, Director Emeritus Briggs states that this book was written at the behest of Secretary of Commerce Henry A. Wallace, who wrote, "... You owe it to yourself, to the Bureau, to the Department, and to the country to shake off some of your customary modesty and let the world know something of what was done." Briggs acknowledges in his Foreword that much of the writing was done by staff members who had participated in the actual work, but these authors are not identified. And sufficient modesty remained in the authors that—from the atomic bomb to concrete ships—only a few names of staff members are given. Nearly no actions or ideas are ascribed to people.

4. ***The Story of Standards,*** by John Perry, Funk & Wagnalls, 1955, 271 pp, is a sprightly collection of stories about the need for standards in many phases of American life before the advent of NBS. In addition, Perry highlights some of the important technical work done at the Bureau during its first 50 years.

Individual Bureau staff members occasionally receive personal mention by Perry, but once again the emphasis is on NBS as an anonymous—though highly effective—force for improved standards.

5. ***Measures For Progress: A History of the National Bureau of Standards,*** by Rexmond C. Cochrane, Natl. Bur. Std. Miscellaneous Publication 275, 1966, 703 pp. This book is a well-written, complete history of the Bureau during its first 50 years of existence. Prepared under the supervision of James R. Newman, a professional historian and well-known scientific editor, it presents comprehensive views of the origin and growth of NBS, its participation in research and development during two world wars, its continually growing standards work, and its intimate involvement with the U.S. standards movement.

In contrast with the writing of his predecessors, Cochrane's book fairly sings about the who and the why of Bureau work. The high level of his scholarship is obvious throughout the text, and the people of NBS, Congress, and the public at large come to life in vivid anecdotal descriptions.

In addition to eight chapters of interesting and informative discussion of the Bureau, set within the framework of the national and international technical scene, Cochrane provides 15 appendices containing many details relative to NBS activities during its first half-century.

6. ***Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards,*** by Wilbert F. Snyder and Charles L. Bragaw (Boulder, CO staff members), Natl. Bur. Std. Special Publication 555, 1986, 842 pp. including 30 chapters, 7 appendices, and an excellent index. Although it is one of several existing histories of particular technical fields at NBS rather than a general history, this book is well worth the time of the interested reader. The authors set out to prepare an account of the work of NBS in the vital and pervasive field of radio. Beginning before the time of the Bureau itself, their text documents the origins of radio as well as the growing body of radio research and service within NBS. Also included is a detailed account of the creation of the radio laboratories at the Boulder, Colorado, site from 1950-54.

7. ***A Unique Institution: The National Bureau of Standards, 1950-1969,*** by Elio Passaglia with Karma A. Beal, *National Institute of Standards and Technology Special Publication 925,* 1999. Elio Passaglia, a long-time Bureau staff scientist, describes the history of NBS during the period 1950-1969. Passaglia's approach and writing skills provide an excellent successor volume to Cochrane's history. The many descriptions of administrative and scientific projects that are presented in Passaglia's book benefit substantially from his background: scientific excellence, particularly in the areas of metallurgy, polymers, and crystallization, as well as experience in a variety of leadership positions at the Bureau, including nine years as chief of the NBS Metallurgy Division. But for his untimely death in 1994, Passaglia no doubt would have been the author of the present volume.

The AD-X2 battery-additive incident, so traumatic for former Director Allen Astin, and the communist-hunting hysteria precipitated by the House Committee on Un-American Activities, which directly affected former Director Edward U. Condon and indirectly affected many others at the Bureau, are recalled in vivid detail in this history. Also recorded are the rise and divestiture of NBS efforts in military research and development during and after World War II. Passaglia's account provides a comprehensive record of the many-faceted activities that characterized NBS during some of its most productive years.

Former Directors of NBS

The Bureau had only five directors during its first 68 years of existence. Significantly, each was a dedicated professional scientist. One could surmise that all issues regarding the agency might first have been approached by these men from the viewpoint of science, rather than that of politics—though none of the five could have been successful without some facility in politics. It is worthwhile to mention these leaders here, because their influence on the young and growing organization was profound.

Similarly potent in determining the orientation—and in many cases, specific activities—of NBS have been the government officials who supervised the NBS Director. These officials included the U.S. Presidents at whose pleasure the NBS Directors served, the Secretaries of Commerce and—when their offices existed—subsidiary officials of the Department of Commerce such as Assistant Secretaries of Commerce for Science and Technology. A chronological listing of these officials is presented in Appendix C.

Cochrane's *Measures for Progress* is an excellent source of biographical information on the first four directors of the NBS. Most of the information for the following sketches have been abstracted from that book.

Samuel Wesley Stratton

The founder and first director of the Bureau was Samuel W. Stratton. Trained in mechanical engineering, physics, and mathematics, Stratton served on the physics faculty of the University of Chicago from 1892 until he was appointed director of NBS in March 1901 by President William McKinley.

First NBS Director Samuel W. Stratton at his desk in the South Building, 1905.

As we noted earlier in this chapter, Stratton was instrumental in the establishment of the Bureau, collaborating with Treasury Secretary Lyman Gage in drawing up a plan for a national standards agency. It was this plan that the Congress accepted in 1901. When the enabling act was passed, Stratton became a logical choice for its first director. Stratton's enthusiasm for the concept led him to accept the post forthwith.

A bachelor whose consuming passion was the practice of science, Stratton devoted himself wholly to making the Bureau strong in its science and in its integrity as an arbiter of standards. He succeeded brilliantly.

Stratton served as director from 1901 until 1922. He saw the NBS staff grow from 12 to more than 850. And as the reader might imagine, he continually testified before Congress, requesting more staff and more funds to accomplish an ever-expanding menu of services. Stratton was successful in making the Bureau grow because he could always demonstrate to Congress' satisfaction that the increased funding led directly to enormous advances in the technical capabilities of the Nation. A graphic example of those advances can be seen in "Miscellaneous Publication 46," mentioned previously, in which more than 50 groups of World War I projects appear; prodigious production for a teen-aged agency!

After leaving the post of NBS Director in 1922, Stratton became the President of the Massachusetts Institute of Technology—indeed, it was the offer of the MIT presidency, coupled with the deaths of three of his long-time Bureau colleagues, that precipitated his departure. His annual salary increased by a factor of approximately three with his new position.

Following his departure from the Bureau, Stratton agreed to become Chairman of the NBS Visiting Committee. His advice to the Bureau thus continued unabated for another eight years.

George Kimball Burgess

The second director of the Bureau, confirmed on April 21, 1923, was George K. Burgess. At the time of his appointment to serve under Herbert Hoover, then Secretary of Commerce, Burgess was Chief of the NBS Metallurgy Division and the senior Bureau physicist.

Department of Commerce identification badge used by George K. Burgess in 1918. At that time he was Chief of the Bureau's Metallurgy Division.

Trained at MIT and the Sorbonne, Burgess worked at NBS in high-temperature research and organized the Metallurgy Division from scratch, turning it within a decade into a 50-man group with international renown.

Burgess proved to have been a felicitous choice as successor to Stratton, being not only a scientist of great competence but also an extremely able administrator. He did not attempt to know all the Bureau projects first-hand, as had Stratton; instead, he concentrated his efforts on careful leadership of his division chiefs. This technique enabled the Bureau to function smoothly even though its staff grew in number to more than 1000 employees. NBS became the largest scientific laboratory in the world and one viewed with great respect for its technical competence.

George K. Burgess, second Director of the Bureau of Standards.

In 1927 Burgess initiated a "Standards Yearbook" "as a companion volume to the Commerce Yearbook."[26] In his "Letter of Submittal," written to Hon. Herbert Hoover, Secretary of Commerce, Burgess succinctly explained his intention:

> I have the honor to submit herewith for publication the first issue of the Standards Yearbook, which will be brought out annually hereafter.

[26] *Standards Yearbook, 1927,* compiled by the National Bureau of Standards, George K. Burgess, Director, BS Miscellaneous Publication 77, 1927. "Price $1.00, clothbound."

Burgess had a grand goal for the book:

> (To) present an adequate picture of the diversification and ramification of the standardization movement which has spread throughout the world with astonishing vitality during the 25 years that have elapsed since the establishment of the National Bureau of Standards.

Within the 250-odd pages of the book, Burgess and his colleagues presented synopses of work done not only at NBS, but throughout both the United States and the rest of the standardizing world; included were summaries of many individual projects in all of these institutions. As might be expected, a comprehensive treatment of this large and growing topic could not long be sustained. The last of the Standards Yearbook series, the 7th, was prepared during the directorship of Lyman Briggs.[27]

Burgess died of a stroke while at his Bureau desk on July 2, 1932. He was not yet 60 years of age.

Lyman James Briggs

The third director of the Bureau was Lyman J. Briggs. As assistant director of NBS for research and testing, he became Acting Director upon the death of Burgess. He was confirmed as Director on June 13, 1933, following the election of Franklin D. Roosevelt to his first term as President.

Trained at Michigan State University, the University of Michigan, and the Johns Hopkins University, Briggs had been personally interested in soil science. He had come to NBS during World War I on an assignment from the Bureau of Plant Industry. Briggs became involved in aviation research at NBS and soon came to enjoy the work immensely. He later became Chief of the Mechanics and Sound Division of the Bureau, a post he held at the time Stratton left NBS.

Burgess appointed Briggs to be Assistant Director for Research and Testing in 1927. Briggs, a modest man, had not particularly wanted the job, but he was well-qualified for it and accepted it the second time it was offered.

Burgess died just as a severe retrenchment in funding and manpower hit NBS as a result of the Great Depression. It fell to Briggs to strive mightily to preserve the Bureau's competence in the face of nationwide unemployment.

An amiable man and a capable scientist, Briggs succeeded in saving the Bureau from destruction during the depression era. Ironically, he subsequently supervised the rapid re-growth in Bureau responsibilities, staffing, and funding that accompanied its heavy participation in military research and development during World War II.

During the directorship of Lyman Briggs, the value of NBS as a national scientific resource was underscored by the events surrounding the initiation of work on the

[27] Briggs nevertheless testified in *his* Letter of Submittal to the Hon. Roy D. Chapin, Secretary of Commerce, that the yearbook was "proving of much value to manufacturers, industrial experts, and engineers, as well as to purchasing agents, both governmental and general" (see BS Misc. Pub. 139, "Price $1.00, clothbound.")

Lyman J. Briggs, third Director of NBS, guided the Bureau through the hard times caused by the Depression and the expansion caused by World War II.

atomic bomb. As detailed by Richard Rhodes,[28] when President Franklin Roosevelt was first approached on October 11, 1939 by Alexander Sachs—acting on behalf of Leo Szilard, Edward Teller, and Eugene Wigner—Roosevelt quickly realized the significance of German work on an atomic bomb and the importance of initiating an American program to counter it.

Roosevelt ordered his assistant, General Edwin M. Watson, to form a small group to investigate the possibilities. Rhodes wrote:

> Watson went by the book. He proposed a committee consisting initially of the director of the Bureau of Standards, an Army representative, and a Navy representative. The Bureau of Standards, established by Act of Congress in 1901, is the nation's physics laboratory, charged with applying science and technology in the national interest and for public benefit. Its director in 1939 was Dr. Lyman J. Briggs, a Johns Hopkins Ph.D. and a government scientist for forty-three years who had been nominated by Herbert Hoover and appointed by FDR. Briggs set a first meeting of the Advisory Committee on Uranium for October 21 in Washington.

[28] Richard Rhodes, *The Making of the Atomic Bomb* (New York: A Touchstone Book published by Simon and Schuster, Inc., 1988) pp 313-315. The author is grateful to Donald H. Tsai for furnishing this reference.

Thus began America's entry into the atomic age.

Briggs celebrated his 71st birthday in May 1945, only a month after the sudden death of Franklin Roosevelt. Within another month, he had submitted his resignation as Director. However, he had no intention to retire to a vine-covered cottage in the country; rather, he desired to return full-time to the laboratory that he had tried not to desert entirely during his tenure as Director.

As we noted in the section on NBS histories, one of Briggs' first post-retirement projects was to write, at the request of Commerce Secretary Henry Wallace, a history of NBS activities during the Second World War.

Briggs may be best known to the general public for his demonstration, more than 10 years after his retirement, that a pitched baseball can be made to curve as much as one-third of a meter as it approaches home plate.[29] Batters and catchers had long known for a fact that good pitchers could throw a curve with "at least a foot of break" to it, but Briggs proved it with scientific instruments, to the delight of baseball fans throughout the Nation. He also wrote two popular articles about the Bureau for the National Geographic Magazine; "Uncle Sam's House of 1,000 Wonders"[30] and "How Old Is it?: Telltale Radioactivity in Every Living Thing Is Cracking the Riddle of Age."[31]

Edward Uhler Condon

The fourth director of NBS (formally appointed on November 7, 1945) was Edward U. Condon, a brilliant physicist who had been in the thick of research on atomic physics and, subsequently, on various World War II projects.

Condon was born, coincidentally, in Alamagordo, NM, site of the first atomic bomb test. He was educated at the University of California at Berkeley and in Germany, where he immersed himself in the new quantum physics. He later served on the physics faculty of Princeton University, collaborating with colleagues on several fundamental advances in the theory of atomic physics and, with George Shortley, writing a treatise on atomic spectra that quickly became a standard text on the subject.

In 1937 Condon was hired as an associate director of research by Westinghouse Electric Corporation: while there, he organized a program of nuclear studies. Later, he helped create a Radiation Laboratory at MIT. In 1943, he became second-in-command to J. Robert Oppenheimer on the Manhattan Project at Los Alamos; his first-hand knowledge of the terrible power of the nuclear-fission atomic bomb led him thereafter to continually seek ways to prevent the use of nuclear energy for weapons of war.

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[29] The scientific reference for this work is Lyman J. Briggs, "Effect of spin and speed on the lateral deflection (curve) of a baseball; and the Magnus effect for smooth spheres," *Am. J. Phys. 27*, 589 (1959). Briggs' demonstration was also reported in many U.S. newspapers, including the *New York Times* on March 29, 1959, and in the magazine *Newsweek* (April 6, 1959).

[30] Lyman J. Briggs and F. Barrows Coulton, "Uncle Sam's House of 1,000 Wonders," *National Geographic 100*, No. 6, December 1951, pp. 755-784.

[31] Lyman J. Briggs and Kenneth F. Weaver, "How Old Is it?: Telltale Radioactivity in Every Living Thing Is Cracking the Riddle of Age," *National Geographic* August 1958, pp. 234-255.

Edward U. Condon, fourth Director of NBS. An accomplished theorist in physics, Condon was blunt, impatient, and inspiring.

Energetic, a clear thinker and a prolific writer, Condon was thoroughly involved in the technical activities of the United States at the highest level.

Condon was not the first choice of Lyman Briggs as his successor. That honor went to Hugh Dryden, a long-time Bureau colleague of Briggs and a distinguished scientist in his own right; Briggs sent Dryden's name to the NBS Visiting Committee for the consideration of Secretary of Commerce Henry Wallace. The committee was slow in transmitting Briggs' suggestion, however, and Wallace, interested in bringing new blood from outside the Bureau to the directorship, was captivated by Condon's obvious qualifications. President Harry Truman agreed with Wallace's choice, and so did the U.S. Senate.

It surprised no one that Condon, once appointed to head NBS, decided that substantial changes in the organization of the Bureau were long overdue. Both the Congressional oversight committees and the senior staff of NBS, used to the gentle demeanor of Lyman Briggs, saw Condon as the proverbial "bull in the china shop."

Under Condon's leadership the NBS administration—indeed much of the staffing—changed markedly. Many of its most senior leaders were of retirement age; many of its most capable technical members had been diverted to war projects, leaving the standards projects understaffed. Perhaps most noticeable of all to Condon, the Bureau organizational structure did not fully reflect the impact of the new science that had developed during the war years. These problems were seen simply as challenges by Condon; with energy and enthusiasm, and not always gently, he attacked them all.

Condon's intellect, his vigor, and his loyalty to America were highly respected by President Truman and by those members of Congress who knew him personally. However, his sometimes caustic *repartee*—particularly noticeable in the presence of slow or mediocre minds—almost certainly annoyed other members. In any case, Condon rather quickly ran afoul of a new phenomenon—the congressional witch-hunt for communists in the Government. Although the Soviets had been U.S. allies throughout World War II, their belligerence after the onset of the Cold War and the fear that they might wrest nuclear leadership from America through the efforts of spies and sympathizers terrified many leaders in and out of Congress.

Condon, like many scientists who were personally able to understand the magnitude of the catastrophe that would accompany nuclear war, advocated disarmament and collaboration with the Soviets to minimize the likelihood of such a war. Because of this attitude, his loyalty to America became a subject of discussion on the floor of the U.S. House of Representatives. He became a prime target for the House Committee on Un-American Activities. Condon's travails during this period were portrayed in detail in Passaglia's history. Here we only note in passing that Condon found them distracting in the extreme as he managed the Bureau and attempted to represent its interests effectively before Congress.

On August 10, 1951, as NBS marked its semicentennial with festivities and technical conferences, Condon announced his intention to resign his directorship. His active public and scientific lives were far from over, but he felt that he had become as much a liability to NBS as he was an asset. President Harry Truman had no reservations about the value of Condon's service; in a letter reluctantly accepting his resignation, Truman praised Condon's scientific standing, his loyalty, and his many accomplishments.

Allen Varley Astin

After Edward Condon resigned, effective September 30, 1951, Secretary of Commerce Charles Sawyer asked the National Academy of Sciences to provide the names of several possible successors to the NBS directorship. One of the people so identified was Allen V. Astin, an Associate Director of NBS who had been designated Acting Director after Condon's resignation. Sawyer submitted Astin's name to President Truman, who appointed Astin in May 1952; the Senate confirmed the appointment on June 12, 1952.

Astin was then but 48 years old, although he had more than 20 years' service at the Bureau. His childhood in Utah had been marked by meager family circumstances that may have been responsible for his strong streak of self-discipline. He worked his way through the undergraduate physics curriculum at the University of Utah, won a scholarship to New York University, and completed M.S. and Ph.D. degrees there. He was awarded a postdoctoral fellowship at the Johns Hopkins University in 1928.

Astin came to NBS directly from Hopkins in 1930. His post was that of a Research Associate on behalf of the Utilities Research Commission of the State of Illinois. Because of the depression, jobs were scarce; however, Astin's work was well received and the Bureau soon was able to hire him full-time to work on a Navy aircraft project.

Allen V. Astin, fifth Director of NBS, photographed in a moment of contemplation in his office on the 11th floor of the Gaithersburg Administration building.

Astin's hiring proved to have been a smart move for the Bureau. His work was fruitful to NBS in the areas of electronics, weather and—after the start of World War II—military ordnance. He became chief of the Electronics and Ordnance Division in 1948. Three years later he was named Associate Director of NBS with oversight responsibility for many transferred-fund projects.

Quiet and reserved, more an emotional twin to Briggs than to Condon, Astin was extremely capable as a manager. That quality was a lucky thing indeed, for it fell to Astin to work through the re-deployment of the Bureau away from war work, and to face a wearing public controversy over battery testing. The reputation of NBS as a rock-solid scientific laboratory and an objective authority on measurement standards was considerably enhanced by the quality of its war work and by the intense scrutiny it survived during the battery-testing ordeal, known as "the AD-X2 incident."

Throughout the whole of his service as Director, Astin remained calm, steadfast in his defense of Bureau objectivity and procedures (which, during the AD-X2 incident, he personally reviewed in detail), and determined to maintain NBS as an effective scientific institution.

The interested reader is urged to follow in Passaglia's history the stories of the shift of NBS attention from work on WW II projects and the intriguing tale of the AD-X2 incident.[32]

The post-War reorganization, requiring the divestiture of many of the NBS staff as various war projects were transferred bodily to other agencies, was a substantial administrative challenge and thus carries its own fascination. During 1953, Secretary of Commerce Sinclair Weeks transferred Bureau personnel working on the proximity fuze project to the Army Ordnance group, where the operation was renamed the Diamond Ordnance Fuze Laboratory. In the same year, the NBS guided missile division at Corona, CA, was transferred *in toto* to the Navy Department. During the next year the Institute for Numerical Analysis, located on the campus of the University of California at Los Angeles, was transferred to the university. Within the space of one year NBS lost 2000 of its 4800 employees.[33]

The battery-testing controversy, which began in 1948, was replete with congressional hearings, newspaper headlines, and charges of Bureau bias against the "little guy." It had the makings of a literary thriller. Astin was relieved of his directorship at one point because of congressional pressure, for " . . . paying insufficient attention to the needs of the marketplace." Astin was reinstated only after public outcry from the NBS scientific staff and from many leaders of the U.S. scientific community. Despite its unblemished record of service to American technology and standards—so recently underscored by outstanding service on WW II military projects—the agency was bullied for many months by the Congress at the behest of one Jess Ritchie, an overly ambitious businessman who attacked the integrity of NBS testing procedures for the benefit of his company.

Ritchie did not want to be told, as he had been many times by Bureau testing personnel, that his storage-battery additive, labelled AD-X2, was of no demonstrable value to a battery's working life.[34]

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[32] Elio Passaglia, op. cit. Other material on this topic is contained in the following references: Elio Passaglia, "Science: Evidence, Truth and Integrity," *NBS Special Publication 690,* January 1985; "Battery AD-X2," *Hearings before the Select Committee on Small Business, United States Senate, 83rd Congress, March 31, June 22, 23, 24, 25, and 26, 1953,* U.S. GPO, 1953; Samuel A. Lawrence, *The Battery Additive Controversy,* Inter-University Case Program Series ICP No. 68, University of Alabama Press, 1962.

[33] See, for example, Elio Passaglia, *Science: Evidence, Truth and Integrity,* NBS Special Publication 690, January 1985, p. 23.

[34] The efficacy of a battery additive is difficult to prove because of the variety and sporadic nature of battery failure mechanisms. NBS test personnel therefore utilized a statistical approach to the testing of such additives. Ritchie much preferred an anecdotal test procedure, one battery at a time.

On June 22, 1953, Jess M. Ritchie demonstrated the battery additive AD-X2 before the Senate Select Committee on Small Business. (AP/Wide World Photos).

In order to force the Bureau to recommend his product, Ritchie organized a high-pressure campaign through individual members of the Congress to call into question the Bureau's procedures and objectivity. Despite Ritchie's charges, the NBS testing was done with great care. Astin himself reviewed the battery-testing procedures and the statistical analyses of the results. The study was conducted strictly by the book.

In early 1953 President Dwight Eisenhower appointed Sinclair Weeks as his new Secretary of Commerce. In turn, Weeks appointed Craig R. Scheaffer, a former president of the Scheaffer Pen Company, to the position of Assistant Secretary for Domestic Affairs. Supervision of NBS was among Scheaffer's duties. Neither Weeks nor Scheaffer was especially tolerant of governmental interference with business.[35] In any case, Ritchie's campaign soon took hold.

Weeks was very conscious of the "heavy burden" that government typically placed on the backs of businessmen; Scheaffer was more than willing to do his part to remove it. Scheaffer recommended that Astin be relieved of his post. Weeks, perhaps unaware of the apolitical heritage of Astin's position, agreed. Astin was called "downtown" and asked to resign, which he did.

[35] Samuel A. Lawrence, "The Battery Additive Controversy," #68 in *The Inter-University Case Program*, (University, AL: University of Alabama Press, 1962), p. 18 ff.

Was that the end of the AD-X2 story? Not quite. There came another campaign, this one mounted by America's scientific establishment. It was enthusiastically abetted by a national press that was critical of what it perceived as a failure of backbone at the Department of Commerce. Leading scientists from several national scientific organizations insisted that the firing of Astin would cripple the ability of NBS to perform its mission—no longer would the Bureau staff be able to undertake testing duties free of political pressure. The senior staff of the Bureau also weighed in with demands for Astin's reinstatement. Hundreds of them threatened to resign if Astin's resignation were to be accepted. This action would have seriously damaged the Bureau's ability to pursue its technical projects—many of them requested by other government agencies.

Ultimately—following an agonizing period of meetings and hearings during which political gears were forced into reverse—Astin was again endorsed as NBS Director by Secretary Weeks. On September 18, 1953, Craig Scheaffer resigned his office. Gradually the AD-X2 matter receded from the public view. NBS emerged from the AD-X2 battle with flying colors and renewed vigor. The agency's methods and integrity had been examined publicly and found to be more sound than nearly anyone outside the organization had ever realized.

Reinstated as Director, Astin continued in office for another decade and a half. His leadership—calm and quiet, but effective—was felt throughout NBS. Technical accuracy, absolute objectivity, and scientific merit remained the norm for Bureau projects.

Having led the NBS for nearly 18 years, including some of the most trying times the agency had ever endured, Allen Astin made known in 1967 his intention to retire in 1969, when he would reach the age of 65. He had served his government and his agency well. His personal involvement in research on proximity fuzes during World War II had contributed to the formation of the Harry Diamond Ordnance Fuze Laboratory. His devotion to high-quality technical work had helped to bring to NBS an outstanding staff, grounded in modern science, in nearly all technical areas. And he had led the Bureau through the stressful period of relocation of its major facilities to Boulder and Gaithersburg.

Astin's personal, scientific, and leadership qualities were recognized by numerous awards. Of these awards, we list only a few. He was the 1947 recipient of His Majesty's Medal for Service in the Cause of Freedom, from England; the Office of the Legion of Honor, from France; the U.S. President's Certificate of Merit in 1948; in 1952 the Department of Commerce Gold Medal Award for Exceptional Service; and the Rockefeller Public Service Award in 1963. He was elected to membership in the National Academy of Sciences in 1960.

At age 65 Astin felt that he was entitled to take a break. No one questioned his decision.

Astin had in mind as his successor a Bureau man who could be expected to raise still higher the level of NBS technical excellence: Lewis Branscomb, a bright, young, Harvard-trained atomic physicist and a proven administrator. However, between Astin's retirement announcement and the appointment of the next director there loomed the 1968 presidential election, already clouded by the unpopular Vietnam War and destined to be further darkened by ugly civil strife. The results of that election would have a definite impact on Branscomb's selection and tenure, as we shall see.

The State of NBS in 1968

In 1968 the National Bureau of Standards occupied an enviable position in the firmament of Federal agencies. A heavyweight contributor to military research and development during two world wars, a highly respected authority on standards of measurement, renowned for the ability of its staff to solve tough scientific and technical problems, NBS was a sparkling asset to the national government.

Let us glance inside this wonderful machine and see what kept it ticking so well when Cyrus Smith left his post as Secretary of Commerce and Lyndon Johnson left the Presidency of the United States.

NBS Facilities

The physical plant of NBS had never been in better shape than it was in 1968. New facilities in Boulder, Colorado, and in Gaithersburg, Maryland, many of them designed especially for complicated projects, provided the Bureau staff with seemingly endless technical capabilities.

The Bureau had begun life in the Coast and Geodetic Survey building at New Jersey Avenue and B Street, in southeast Washington, DC. It was not an environment well-suited to breakthrough standards research; 14 people, including the night watchman, occupied the designated space in the modest building. Such a tiny agency could provide only minimal standards services to the Nation.

One of the initial projects of its founding Director, Samuel Stratton, was to obtain larger and better facilities for the new agency. Stratton relieved the immediate space problem by acquiring two buildings standing near the Coast and Geodetic Survey offices. He also sought a larger, permanent home for the Bureau. In this endeavor he had the assistance of the first Visiting Committee. They quickly selected an 8-acre wooded site about 3 1/2 miles from the White House along Connecticut Avenue, at the end of Washington's trolley line.[36]

This setting provided NBS with its main laboratories for more than 60 years. Periodic expansion of the duties and staff of the Bureau was accommodated by acquiring adjoining land for new laboratory construction; purchases in 1913, 1918, 1920, 1925, 1930, and 1941 gradually increased the size of the Bureau site from its initial 8 acres to just over 70 acres. Until the construction of a new site at Gaithersburg, however, there never was an administration building to house the Director, his staff, and the central service activities.[37]

The Bureau occupied many small, special-purpose sites during its decades of service.[38] These sites included both occasional and semi-permanent or permanent laboratory space acquired for a variety of purposes:

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[36] See MFP, p 62.

[37] Robert S. Walleigh, "The Gaithersburg Site," in *NBS/NIST: A Historical Perspective,* NIST Special Publication 825, April 1992, p. 49.

[38] See MFP, App. J.

Aerial view of the Bureau of Standards campus in Washington, D.C., circa 1922.

1. The study of structural materials occurred in:
   - Allentown, Pennsylvania.
   - Atlantic City.
   - Denver.
   - Kansas City.
   - Northampton, Massachusetts.
   - Pittsburgh.
   - Permanente, Riverside and San Jose, California.
   - Seattle.
2. Railroad-car testing was done in Clearing, Illinois beginning in 1928, to serve the needs of the Nation's railroads.[39]

[39] "NBS Railroad Track Scale Project—What and Why," *NBS Standard,* Vol XV, No. 9, September, 1970, pp. 1, 3. In 1981, this program, involving two calibration personnel, two specially equipped railway track scale test cars, and a depot in Clearing, Illinois, was transferred to the Federal Grain Inpsection Service.

In 1910, the Secretary of the Interior transferred the staff and equipment of the Geological Survey's structural materials laboratories to the Bureau of Standards. These included a Pittsburgh laboratory where cements for navy yard and dry dock construction, as well as clays, ceramics, lime, steel, and other structural materials were tested. This photograph of the Pittsburgh laboratory was taken in 1913.

3. Radio field stations girdled the globe:

- Anchorage and Point Barrow, Alaska.
- Antarctica.
- Kitt Peak Observatory in Arizona.
- Australia.
- Bolivia.
- Brazil.
- California.
- Canada.
- Canary Islands.
- Canton Islands.
- Chile.
- Colombia.
- Nearly 20 sites in Colorado.
- Ecuador.
- Greenland.

- Guam.
- Hawaii.
- Iceland.
- Illinois.
- India.
- Japan.
- Kenya.
- Malagasay.
- Malaya.
- Maryland.
- Minnesota.
- Missouri.
- Morocco.
- Nebraska.
- New Jersey.
- New Mexico.
- New Zealand.
- Nigeria.
- Okinawa.
- Oklahoma.
- Panama Canal Zone.
- Peru.
- Philippines.
- South Africa.
- Sweden.
- Puerto Rico.
- Trinidad.
- Virginia.
- West Indies.
- Wyoming.

4. A lamp inspection station was established in Brookline, Massachusetts.
5. The Institute for Numerical Analysis was created in Los Angeles.
6. Electronics testing was performed in LaPlata, Maryland, and Tuckerton, New Jersey.
7. Aircraft landing equipment was tested in Arcata, California.
8. The Joint Institute for Laboratory Astrophysics was established at the University of Colorado in Boulder.
9. The Clearinghouse for Federal Scientific and Technical Information was placed in Springfield, VA.
10. A laboratory for electronic research and development, including the development of guided missiles, was established in Corona, California.

The so-called "field stations"—some small, some large—tended to come and go as the Bureau responded to its commitments. For many years, though, the sun did not set on the NBS "empire."

By the time Edward Condon became its director in 1945, the Connecticut Avenue facilities had become overcrowded and seriously outdated or run-down. More than 100 buildings dotted the site, some constructed for special projects during the First World War. Bureau personnel occupied space in a haphazard manner—the staff of one technical division was quartered in 17 different buildings.[40] Personnel from the Public Buildings Administration, a Federal housekeeping agency, who were asked to evaluate the condition of NBS property during the mid-1950s, found many buildings that could only be described as decrepit. There were few records of the locations of the utilities for the various buildings—information that was essential to even attempt repairs for them. No funds had been provided for maintenance of the Connecticut Avenue site for years, and the buildings showed it.

[40] Robert S. Walleigh, "The Gaithersburg Site," p. 49 in *NBS/NIST: A Historical Perspective,* NIST Special Publication 825, Karma A. Beal, editor, April 1992.

The NBS Visiting Committee had frequently made Congress aware that the work of the Bureau was hampered by the limitations of its main facility on Connecticut Avenue; Congress' own assessment in 1947 supported that claim. Congress responded to this case of clearly documented need with a decade of cogitation and study.

Finally, in 1957, the Congress decided to permit the acquisition of a new principal location for the Bureau in Gaithersburg, Maryland. Strangely enough, by that time the ice had been broken by the creation of a major laboratory in Boulder, Colorado, as we shall see.

Congress' decision to relocate the main Bureau facility was only partly motivated by the obvious crowding and decrepitude of many of the Connecticut Avenue buildings. Another consideration at that time was the desire to disperse vital governmental activities in case there should be a nuclear attack on Washington. A third motivation was the substantial need for special laboratories that couldn't be located "in town" because of space or technical requirements.

A priority that influenced the selection of the new principal site was that of continuing to work on vital tasks during the course of a move. Although many specialized projects could not be undertaken at all in the old laboratories, many other activities were in progress despite the cramped quarters; some of those would suffer if the move entailed a long down-time.

The Boulder Site

Congress dithered over a move of the main NBS laboratory complex for a decade.[41] However, not all of the Bureau's assigned tasks could wait that long. Radio science was one of these. As matters turned out, cryogenic engineering was another.

The field of radio research included a whole set of projects that awaited a better environment. The area around the Connecticut Avenue site, no longer a quiet residential location, teemed with traffic, commerce, and the attendant vibration and electrical noise. Washington, DC, like any large city, was deluged by radio and other electromagnetic signals. High-power commercial stations broadcast their messages widely. Just as pervasive were radio communications networks run by police, air and ground transportation services, colleges, hospitals, and a multitude of other entities. Radio quiet and long sight-lines, essential for effective development of new standards for radio communication, no longer were available in the Nation's capital.

The Central Radio Propagation Laboratory (CRPL), organized as a division of NBS in 1946 to consolidate and broaden the work of the wartime Interservice Radio Propagation Laboratory, was the focus of the arguments for a new site. The military Joint Chiefs of Staff had urged Commerce Secretary Henry Wallace in 1945 to establish within the Bureau a central source for the dissemination of information on

[41] Wilbert F. Snyder and Charles L. Bragaw, *Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards* Natl. Bur. Std. (U.S.) Special Publication 555, October 1986. The Boulder move is described in Ch XIX. The transfer of the Central Radio Propagation Laboratory to the Environmental Science Services Administration, later known as the National Oceanic and Atmospheric Administration, is discussed in Ch. XX.

radio transmission and for conducting research on radio propagation. In turn, Wallace, early in 1946, asked the Director of NBS to create a Central Radio Propagation Laboratory. Edward Condon, then NBS Director, established the CRPL as Division 14 of the Bureau as of May 1, 1946. The activities formerly conducted by the Radio Section of the Electricity Division were transferred to the new division. J. Howard Dellinger was named Chief of the CRPL; his deputy was Newbern Smith.

At the first meeting of the Radio Propagation Executive Council—formed specifically to advise the CRPL staff on its programs—Dellinger noted the inadequacy of existing Connecticut Avenue facilities and described plans to erect a new building there. But these plans changed when the laboratory leaders realized in 1948 that they really needed a location with less interference and more open space, as well as access to a larger variety of terrain than could be found locally.

Once the decision was reached to seek a new location for radio work, three criteria for choosing it were developed. The new site had to be free, or nearly free, of electromagnetic interference for radio communications; it had to feature long lines of sight; and it must be near a good university-level electrical engineering department. Boulder, Colorado, Charlottesville, Virginia, and Palo Alto, California, seemed to be suitable choices. Boulder's location, with tall mountains on the west and flat plains on the east, offered the prospect of excellent sight lines; moreover, it was favored by Director Condon. The Boulder Chamber of Commerce clinched the choice with an offer of some 200 acres of land—purchased with money raised by public subscription—to be given to the Federal government for the site.

Persuaded by the endorsement of the Joint Chiefs of Staff and the gift of a site, Congress endorsed the relocation of NBS radio research to Boulder.

As soon as the Boulder site was selected, planning for a new radio building began. The chosen design utilized reinforced concrete to produce a solid, long-lasting structure. A central spine was to be flanked by an auditorium and a library near the front, and by six perpendicular wings in the rear. The structure was to be set into the sloping land south of Boulder, with Green Mountain and the Flatiron rock formation behind it.

Construction on the Boulder site began in 1951—but, surprisingly, not for the radio laboratories!

Even before the Central Radio Propagation Laboratory mounted its crusade for a new environment—during the latter days of World War II—the hydrogen bomb had entered the national picture, though only in the form of highly secret calculations and experiments. Later, in 1949, the U.S. Atomic Energy Commission (AEC) became aware that the U.S.S.R. weapons program had caught up in the international arms race by producing an "atomic" bomb—one utilizing the principle of a neutron-induced chain reaction to propagate nuclear fission throughout a mass composed mainly of ^{235}U. Fearful of losing America's lead in munitions, the Defense Department and AEC leaders decided to mount a crash program to produce a still more powerful bomb, the "Super" thermonuclear weapon.

Aerial view of the National Bureau of Standards Boulder, Colorado laboratories and the nearby Rocky Mountains.

Declassified reports indicate that the Superbomb concept originated in discussions between Enrico Fermi and Edward Teller during the development of the fission bomb that was used during the summer of 1945 to bring World War II to a close in the Pacific theater.[42] Essentially, the idea behind the Superbomb was to use the enormous heat and pressure generated by a fission bomb to initiate nuclear fusion in hydrogen, unleashing potentially 1000 times the energy of a fission bomb. In fact, it appeared that the fusion of deuterium (^2H) nuclei with other deuterium nuclei, or the fusion of tritium (^3H) nuclei with deuterium nuclei, might provide even higher reaction rates than would the fusion of two ordinary (mass-1, ^1H) hydrogen nuclei. A workable bomb, it was thought, might be assembled using large amounts of liquid hydrogen, liquid deuterium, or liquid tritium—a highly radioactive isotope—in conjunction with a fission-bomb "detonator."

[42] F. G. Brickwedde, E. F. Hammel, and W. E. Keller, "The History of Cryogenics in the USA," Chapter 11 in *History and Origins of Cryogenics*, R. Scurlock, ed. (Oxford: Oxford University Press, 1992).

Thus it happened in 1950 that liquid hydrogen and expertise in cryogenics—both in large quantities—were wanted by the Atomic Energy Commission, and quickly. Seeking an appropriate laboratory where such Cold War weapons could be located, the AEC considered the new Boulder site chosen by NBS. Not only did the Bureau possess considerable experience in cryogenics, but the newly acquired location at once offered relative isolation from congested areas, yet relative proximity—only 400 miles!—to the Los Alamos laboratory.

The Bureau was well known to the AEC and highly respected for its "can do" spirit on many WW II projects. Furthermore, at its Connecticut Avenue site NBS housed a cadre of highly qualified low-temperature physicists and engineers including Ferdinand G. Brickwedde (Chief of the Heat and Power Division), Russell B. Scott (Chief of the Cryogenics Section), John R. Pellam, Emanuel Maxwell, and W.E. Gifford.[43] In fact, Brickwedde's work at NBS on the properties of liquid hydrogen had led Harold C. Urey to collaborate with him in 1931-32 on work that established the very existence of deuterium as an isotope of hydrogen.[44]

The presence of Brickwedde, Scott, and their colleagues in the NBS low-temperature laboratory, plus the favorable location of the Boulder site, appeared to the AEC to be just the ticket for the creation of a large supply of liquid hydrogen within the confines of a versatile cryogenic engineering laboratory. The laboratory would be safely isolated, yet part of the NBS complex. The AEC suggested to Congress that a cryogenics laboratory should be established immediately at the NBS/Boulder site. The recommendation was quickly approved.

Work on a monster hydrogen liquefier began immediately in the Washington cryogenics laboratory. Brickwedde assembled a team comprising himself, Scott, and Gifford from the NBS Cryogenics Section and he added Victor J. Johnson, a low-temperature engineer from the Naval Research Laboratory, also located in Washington. Within one year's time the team had designed and built a hydrogen liquefier expected to produce 350 liquid liters per hour—10 times the capacity of the largest plant previously in use.

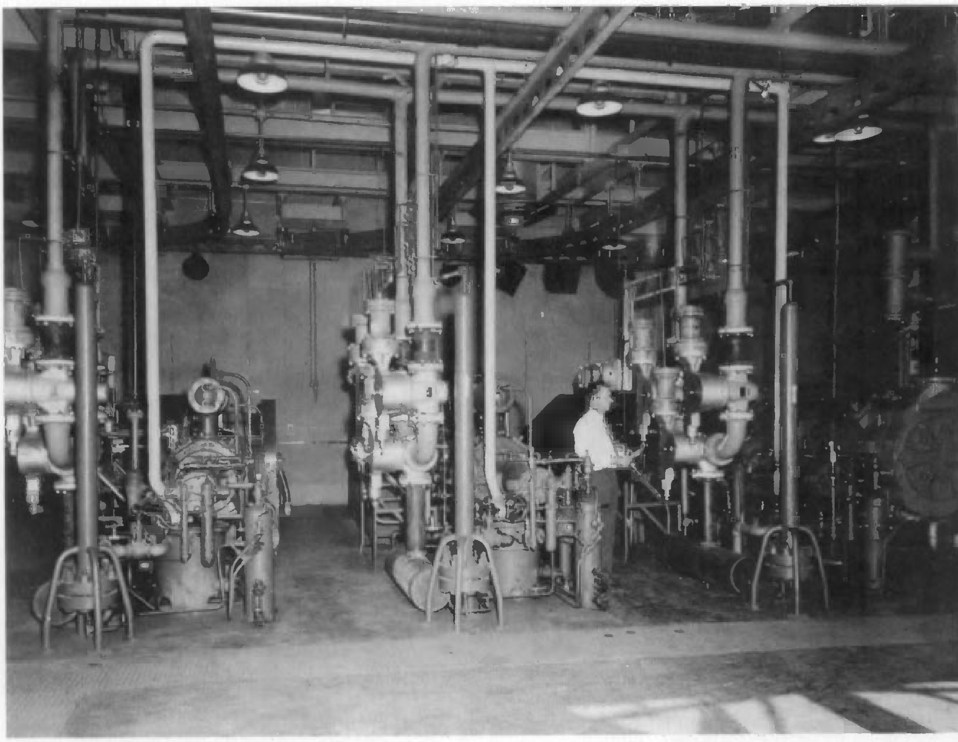
It was because of this intense effort in cryogenics that, instead of an advance team from the Central Radio Propagation Laboratory, the first NBS staff to inhabit the Boulder location was a group of low-temperature experts—sometimes called "cryogenists"[45] but, more often, "cryogenicists"—under the direction of Russell Scott. The group included Gifford, Johnson, Dudley Chelton, Bascom Birmingham, Robert B. Jacobs, Peter C. Van der Arend, Richard Kropschot, and Robert L. Powell.

The hydrogen liquefier occupied a large building—about 1,300 square meters (14,000 square feet) in floor area—whose principal external distinguishing feature was a set of large ventilators that helped to change the air in the entire building every

[43] See Brickwedde, Hammel, and Keller, op. cit.

[44] This work helped Urey to earn the 1934 Nobel Prize in chemistry. A concise but readable account of the work can be found in Daniel J. Kevles, "The Physicists: The History of a Scientific Community in Modern America" (Cambridge, Massachusetts: Harvard University Press, 1971) pp. 225-226.

[45] From the Greek "cryo" and "–geny," the creation of low temperatures.



Victor J. Johnson in front of a bank of air-operated selector valves connecting hydrogen compressors to hydrogen liquefying systems in the Boulder Cryogenic Engineering Laboratory.

two minutes, a very desirable safety feature. As part of the hydrogen-liquefier project, a second liquefier capable of producing 450 liters of liquid nitrogen per hour was also built. The liquid nitrogen was used to pre-cool gaseous hydrogen prior to its liquefaction. The whole plant was heavily instrumented to provide information for eventual optimization of the liquefaction process.[46]

The hydrogen liquefier was the first installation in an extensive cryogenics laboratory that gradually took shape at the NBS/Boulder site.[47] Besides the liquefier building, the cryogenics complex included an even larger—1,860 square meters—main laboratory building and a half-dozen smaller, special-purpose buildings.

The rapidly expanding cryogenics group initiated engineering studies of fundamental phenomena such as the exothermic ortho-para conversion process in hydrogen, augmented by a multitude of projects on the production, handling, transport, and instrumentation of cryogenic fluids and solids.

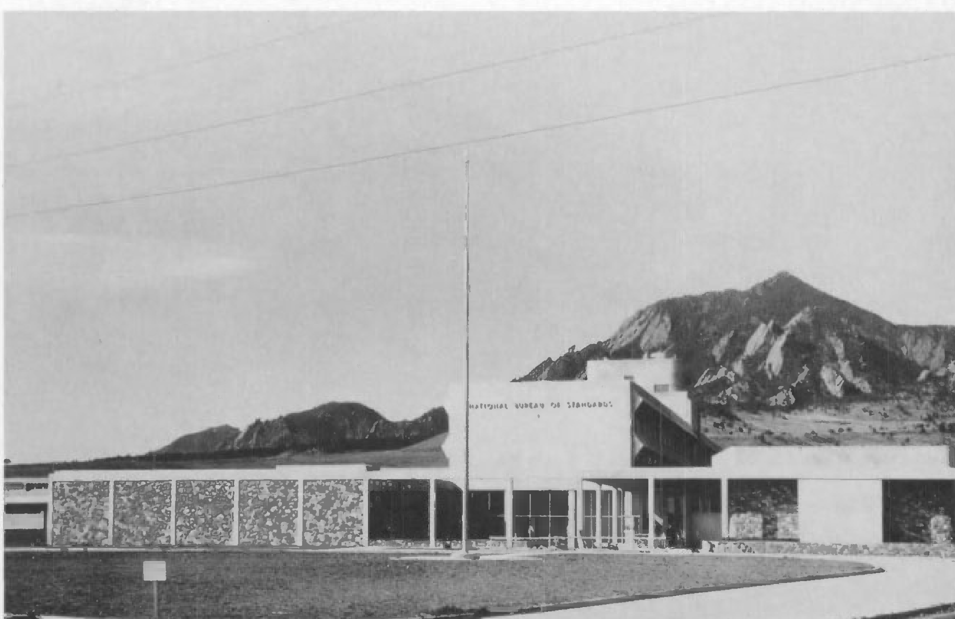
[46] Russell B. Scott, Cryogenic Engineering (Princeton, NJ: Van Nostrand, 1959).

[47] Snyder and Bragaw, *Achievement in Radio,* p 720; Robert A. Kamper, "History of the Boulder Laboratories," p. 43 in *NBS/NIST: A Historical Perspective,* Karma A. Beal, editor, NIST Special Publication 825 (Washington, DC: U.S. Government Printing Office, 1992).

We shall have much more to say about low-temperature science at Boulder as our history continues. However, we should note here that, with the success of the 1951 "George" experiment in the AEC's "Greenhouse" thermonuclear-fusion test series, the principle of thermonuclear ignition was proved. With the "Mike" shot at Eniwetok at the end of 1952, the great explosive force of the "Super"—the equivalent of about 10 megatons of TNT, dwarfing the kiloton yields of fission bombs—was demonstrated. The thermonuclear project involved very substantial advances in cryogenic engineering—not just at NBS but by a whole consortium of laboratories. However, the cryogenics staff of the Bureau played a vital part in proving that America could harness the energy of the stars through the use of isotopes of hydrogen in liquid form.

Construction of the main radio laboratory building began in 1952. On September 14, 1954, President Eisenhower led a distinguished group to Colorado to dedicate the new Boulder NBS laboratories.

The detailed history by Snyder and Bragaw provides evidence aplenty of the mushrooming demand for radio services that accompanied the opening of the new laboratories. As just one example, the Air Force asked for a whole group of new calibration and advisory services in radio while the Boulder expansion was still under study. Planners estimated that an additional facility costing $5 million should be added to the projected building expenditures just to satisfy the new Air Force needs.



Administration Building for the National Bureau of Standards Boulder, Colorado laboratories.

By 1968, the Boulder complex included the large Radio building, a Cryogenics building, a hydrogen-liquefier building, a plasma-physics building, and about a dozen other structures. In addition to these facilities on the main site south of town, Bureau scientists assigned to the Joint Institute for Laboratory Astrophysics shared with their University of Colorado colleagues a new building on the CU campus. It was completed only in 1966 with funds from the National Science Foundation and the university. Appendix D includes a map of the NBS/Boulder site.

The Gaithersburg Site

The move of the main laboratories of NBS away from its outgrown home on Connecticut Avenue was eased considerably by the success of the Boulder enterprise. There was no question that a move to new and substantially larger quarters was necessary if the Bureau was to continue to meet its responsibilities to the nation's technical enterprise. The only cause for concern appeared to lie with the potential disruption of ongoing projects that might accompany a move. The Visiting Committee advocated retention of the Connecticut Avenue campus as late as 1957, at the same time citing the pressing need for immediate relief for certain projects from the conditions existing at the old site.

Finally fully aware that NBS—a valuable national resource—could hardly prosper in the cramped, outmoded Connecticut Avenue site, Congress in 1956 decided to permit the main laboratories to take the same step taken earlier on behalf of radio science and cryogenics; an entirely new campus.

At once, defining questions needed answering: Where should NBS relocate? How much money would relocation cost? How should the Bureau plan the new facilities? Could a move take place without interrupting or destroying the continuity of the Nation's physical standards?

Responsibility for overall planning of the move was given to Robert Walleigh, NBS Associate Director for Administration, an engineer by training and a Bureau employee since 1943. Walleigh went to work immediately on the task.[48]

Where should NBS relocate? At least 20 miles from the White House, according to the criterion of dispersing government facilities to reduce the potential for damage by nuclear attack. Not much farther than 20 miles, by the practical criterion that unbearable staff attrition might accompany a move to a distant place. Of some 100 sites recommended for study by a task group composed of NBS personnel and members of the Public Buildings Service (a division of the General Services Administration), a 550-acre expanse of farmland near Gaithersburg, Maryland, was chosen by Director Astin with the advice of Walleigh and other planners.

Relocation to nearby Maryland—a short automobile ride from the Van Ness site—mitigated the fear of interrupting Bureau services during the move. The staff simply could—and did—carry certain critical instruments in their own vehicles to minimize downtime and the likelihood of damage.

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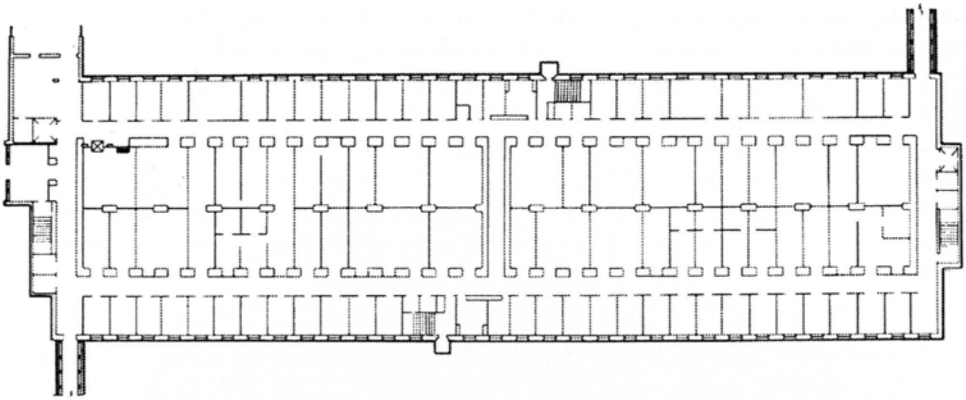
[48] Robert S. Walleigh, "The Gaithersburg Site," in *NBS/NIST: A Historical Perspective,* NIST Special Publication 825, April 1992, pp. 49-55. See also the NBS Annual Report for 1966, Miscellaneous Publication 283, April 1967; and the NBS Technical News Bulletin for November 1966.

On October 24, 1961, a red oak was planted at the new, as yet undeveloped Gaithersburg, Maryland site in honor of Director Emeritus Lyman J. Briggs. Briggs shoveled the first dirt on the tree while William R. Stevenson held it in place and Director Allen V. Astin stood by.

How much money would relocation cost? Asked this question on short notice by Congress, the NBS management consulted the General Services Administration. GSA personnel performed a quick estimate of the cost of constructing a single building with no special facilities and came up with the number $40 million, lower than the eventual cost by nearly a factor of four. The unrealistic GSA estimate would haunt NBS management for years to come.

How should the Bureau plan the new laboratory facilities? An architectural firm with experience in designing laboratory space for the Bell Telephone Laboratories, for the E.I. DuPont de Nemours Co., and for the Ford Motor Co. was engaged. An NBS Gaithersburg Planning Committee was selected to work with the architects and the technical staff. A laboratory planning committee composed of senior, active Bureau staff members began thinking about the optimum design of new laboratory space. A wide range of possibilities—from specially designed laboratories in a single building to a group of buildings containing simple, cinder-block rooms to permit maximum flexiblity—was considered by the planners. Ultimately, a combination of connected general-purpose laboratory buildings, plus separate special-purpose structures, was chosen. Use of cinder-block construction, however, was not approved for the buildings.



Floor plan of general-purpose laboratories at the National Bureau of Standards in Gaithersburg, Maryland. Experimental spaces were located in the central portions of the buildings, offices along the exterior walls.

Minimizing the effects of electromagnetic interference, a constant problem at the Van Ness site, was tackled by Clarence J. Saunders. Saunders, a Bureau veteran of many years' standing, assisted Walleigh in planning the electrical grounding and shielding systems.[49]

Further emphasis on the importance of better facilities for NBS, had any been needed, came from outer space! When the Soviets launched Sputnik I on October 4, 1957, they inadvertently intensified the desire of the U.S. Congress to improve America's technological capabilities. Suddenly, science became a more important national enterprise than it had been before the little beeper orbited the earth.[50]

Planning of the new laboratories was thorough. Each project leader was permitted to suggest modifications to a standard modular design used in the general-purpose laboratories so that the space could meet special requirements. Special buildings were planned to house one-of-a-kind activities; Walleigh was adamant that no poorly constructed or temporary buildings should be allowed on the site.

Construction of the facilities comprising the Gaithersburg complex began in 1961. Appendix D provides information on the progress of construction through 1990. Although most of the construction was completed within 7 years, a new major laboratory building was under construction even as this history was written. Most of the structures shown on the accompanying map were built during the initial construction period.

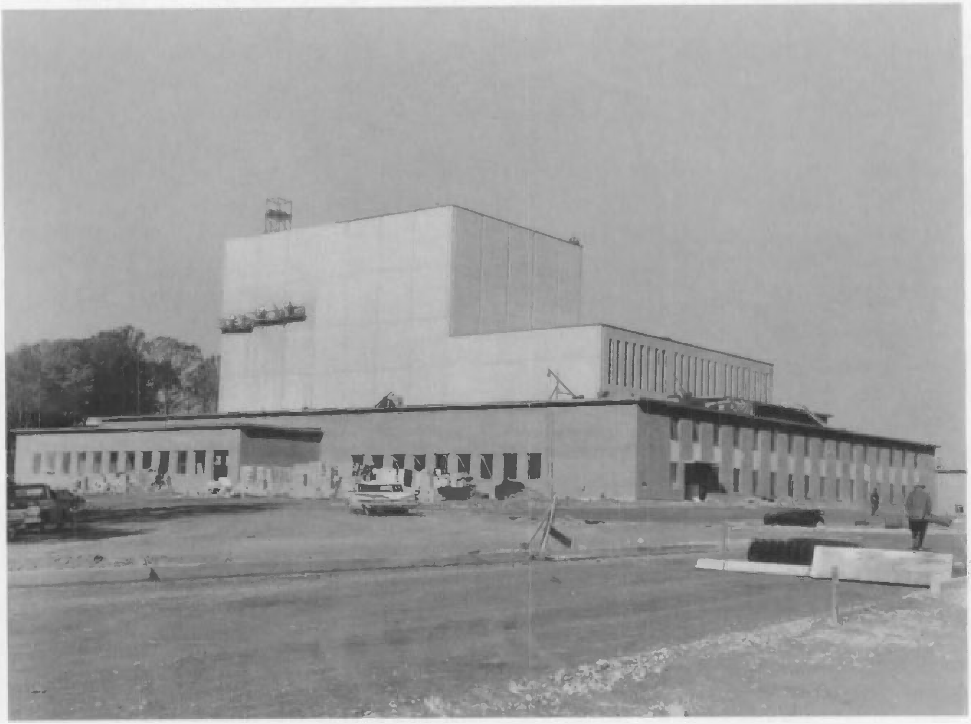
The overall plan for the Gaithersburg complex called for a central electrical power station and a central air-cooling facility. Both services would be available for all

[49] "The importance of electromagnetic compatibility at NBS," *NBS Standard,* Vol XV, No. 3, March 1970, pp. 1, 4.

[50] See, for example, pp. 421-423 in *Hearings Before a Subcommittee of the Committee on Appropriations, House of Representatives, 85th Congress, Second Session* USGPO (1958).

buildings *via* underground supply lines. Laboratory buildings would be furnished with cooled, dried air which would be heated in each building as needed.[51]

The first of the laboratory buildings to be built on the Gaithersburg site was the Engineering Mechanics building. It would house calibration equipment for load cells, force measurements, proving rings, creep measurements, "deadweight" machines, and dynamic materials testing. The needs of NASA and the Department of Defense for calibrations of high-thrust rockets were critical, so construction—at the intersection of Center Drive and South Drive—was begun as soon as possible in 1961. The building took two years to complete. The pressing need for large-force calibrations led the staff to begin work several months prior to completion.



The National Bureau of Standards Engineering Mechanics Building in Gaithersburg, Maryland. It was built to house a one-million-pound dead-weight tester.

Construction of the Radiation Physics building was started during 1962. At the same time, the Supply and Plant and the Instrument Shop service buildings were begun. The following year, a Nuclear Reactor facility was begun near the Radiation Physics building. When occupied in 1964 and 1965, respectively, these two laboratories provided

[51] This plan worked well. The only hitch developed because typical general-purpose laboratory electronic equipment, expected to consist largely of hot vacuum tubes, instead incorporated relatively cool electrical transistors, thus placing unexpectedly large demands on the laboratory re-heat systems.

the core of a Center for Radiation Research. The capabilities that were thus created soon placed NBS in the forefront of research and standards in these areas. The Radiation Physics structure incorporated an electron linear accelerator and a number of other radiation-producing machines and sources to support a wide range of research and standards capabilities. The NBS research reactor—since upgraded from 10 megawatts to 20 megawatts—quickly became a national resource, with programs of dosimetry, activation analysis, isotope production, and fundamental studies involving cold neutron fluxes and materials analyzers.[52]

Visitors to the new Bureau facility in Gaithersburg usually first saw the Administration Building as they approached the site; eleven stories high, it towered over all the other buildings. Most administrative functions of the Bureau were located there. Integral with it were two auditoriums, the main library, the central computer, a large cafeteria, sundry lecture rooms and other smaller facilities including a bank, a barber shop, and a gift shop. Construction of the administration-building complex was begun in 1962; it was first occupied in 1965.

A tree, reputed to be a direct descendant of the legendary apple tree that prompted Sir Isaac Newton to propose his law of universal gravitation, was planted in the library courtyard at the Gaithersburg site. The NBS Administration Building appears on the right-hand side of the photo.

[52] Reactor Radiation Division: Annual Progress Report, NBS Technical Notes 567 (1970), 714 (1971), 758 (1972), 813 (1973), 860 (1974), 896 (1975), 939 (1976), 969 (1977), 995 (1978), 1117 (1979), 1142 (1980), 1160 (1981), 1178 (1982), 1190 (1983), 1207 (1984), 1217 (1985), 1231 (1986), and 1257 (1988).

Seven general-purpose laboratory buildings—some of them built with three stories above ground and one below, others without basement space—were connected to the Administration Building by a central hallway two stories high. These buildings were named for scientific and technical disciplines involved in Bureau work—Metrology, Physics, Chemistry, Materials, Polymers, Technology (initially known as Instrumentation) and Building Research. Each of these except the one devoted to Building Research was constructed with peripheral offices separated by corridors from central laboratory spaces. This design eased considerably the problem of stabilizing laboratory temperatures, since sunlight—with its variable heating rate—was excluded from the laboratory space.

The Building Research laboratory was constructed with a view to testing structures on a large scale. Sections of bridges, piers, walls, and other structural components could be subjected to mechanical or thermal stresses in a variety of modes—indeed, one project featured a test of the efficiency of the thermal insulation in an entire modular home.

Construction of all the general-purpose laboratories was begun in 1963, and all were occupied by the end of 1966.

A pair of small, special-purpose buildings devoted to the study of low-level magnetism were built behind the Nuclear Reactor building. Construction was begun in 1964, and they were first occupied in February 1968. These buildings had the interesting distinction of having been constructed without the use of ferromagnetic materials—no steel nails, no iron reinforcing rods, no steel conduit for electrical wires.

The Sound building, dedicated to the study of acoustic phenomena, featured a large anechoic chamber and a reverberation chamber as well. It was begun in 1965 and occupied early in 1968. It was located between West Drive and Gate C.

During 1966, construction of the Hazardous Materials building, the Concreting Materials building, and the Industrial building was begun. Like the Sound building, these were good examples of separate, special-purpose buildings on the Gaithersburg site built to accommodate specific technical projects. One of these projects was a study of the properties of a mixture of liquid sodium and potassium, used as the primary coolant for certain nuclear reactors because of the low neutron-capture cross-sections of these two elements. This mixture was extremely dangerous to handle; it could combine explosively with several ordinary materials. The Hazardous Materials building was built to isolate such projects. The building was placed on the southern edge of the grounds, well away from the general-purpose laboratories. It was first occupied during 1968. The Concreting Materials building took two years to complete; its service life also began during 1968. The Industrial building, containing special equipment for the study of paper making and textiles, also was completed and occupied during 1968.

The Fluid Mechanics building was built across South Drive from the Engineering Mechanics building. Begun in 1967, it was completed and occupied two years later. Specialized studies of the flow characteristics of a variety of fluids could be accomplished on a routine basis in this building.

Although the Bureau's fire-studies program was among its oldest endeavors, work on a Fire Research building was begun only in October, 1973, in response to a national outcry for more effort in fire prevention. The Fire Research building was occupied in April 1974 and dedicated on June 25, 1974. However, it was regarded as complete only during October, 1975. Like the Hazardous Materials building, it was placed somewhat away from the general-purpose laboratories for added safety. In the Fire Research laboratories, entire rooms full of furniture could be heavily instrumented and then burned in order to observe the nature, progress, and noxious products of fires typical of all types of residential and commercial buildings.

An unusual circumstance permitted interesting studies of the cost savings that could be realized by retrofitting an ordinary home with modern thermal insulation. The Bowman House, an existing rural residence which NBS had more or less inadvertently purchased along with the rest of the new grounds, was used for the insulation study by the Building Research Division. The useful life of the building was extended in a uniquely satisfying manner when it was given over to an on-site child-care program after completion of the thermal study.

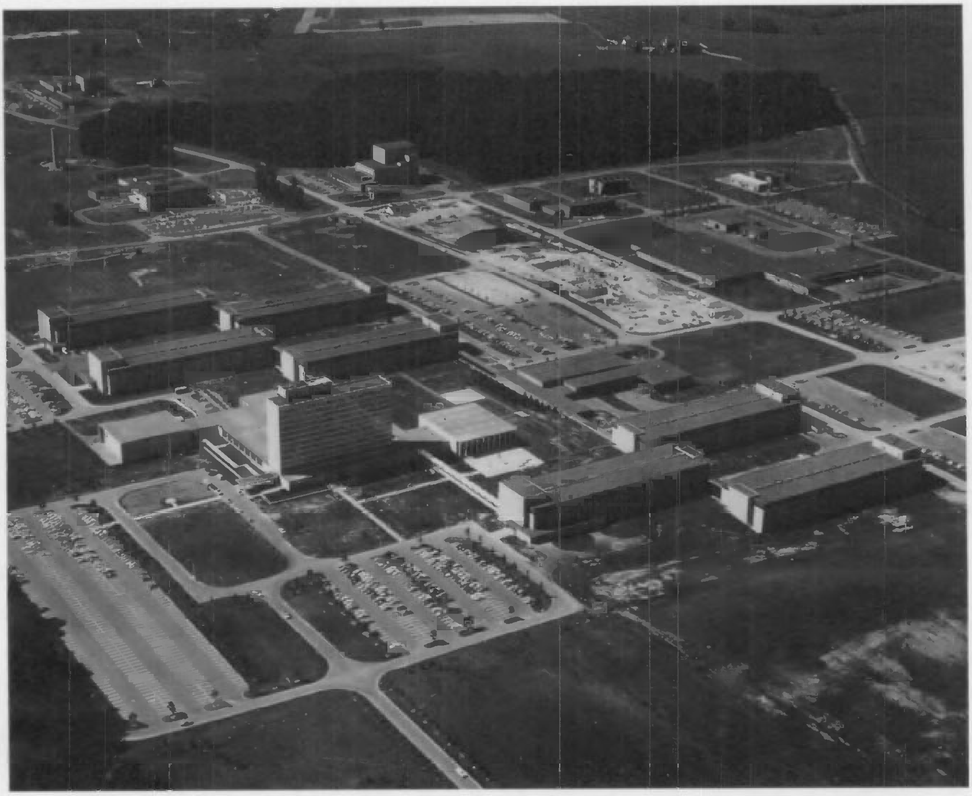
As each building was completed, the occupying groups measured the new space against plans they had prepared prior to the construction. In fact, many—if not all—had designated one or more staff members to monitor the progress of the construction. These people planned and tracked the placement of group property in the new space, with special emphasis on the well-being of experimental apparatus. Nearly everyone moving into the new quarters felt that metrology and science at the Bureau were about to move up a notch.

Although many buildings were constructed on the Gaithersburg site, its large area still provided a park-like setting. The extensive grounds had been requested by the Bureau planners to provide a buffer against the electrical and mechanical disturbances that plagued the old site. Together with an absence of heavy industry near the site, achieved through an agreement with the Montgomery County government, the encircling open space proved effective in forestalling the encroachment of both types of interference as the nature of the surrounding area changed from rural to urban. The use of steel in the construction of the walls of most of the buildings played a role as well in shielding sensitive experiments against electromagnetic interference.

From the beginning of the Bureau's occupation of the Gaithersburg site, a small herd of deer (originally approximately five in number) inhabited the area inside the boundary fence. The protection of the fenced Bureau grounds allowed these few animals to increase steadily to a very noticeable herd of several hundred. The deer lent a sylvan beauty to the site, but the price of that beauty was the ravaging of many decorative plants that contributed to its extensive landscaping.[53] Canada geese, too, proved a mixed blessing. Attracted by the large expanse of grass and two ponds placed on the grounds as emergency water sources,[54] they inhabited the grounds on a

[53] Among the plantings on the Gaithersburg site were nearly all of the azaleas from the Van Ness NBS grounds. These plants were quickly destroyed by the deer.

[54] Robert S. Walleigh, personal recollection.



Aerial view taken in 1966 of the new National Bureau of Standards laboratory complex in Gaithersburg, Maryland.

year-round basis. Like the deer, they found NBS a hospitable landlord. It was not unusual to see a nesting goose outside a window that featured predictions of hatching dates and other information on a placard. Unfortunately, the unrestricted goose population made for messy sidewalks and roadways.

The official dedication of the Gaithersburg laboratories took place in November 1966, after about 90 percent of the staff had moved to the new site. Left behind were several groups, including the Fluid Meters, Hydraulics, and Aerodynamics Sections—the last to move to the Gaithersburg site, in 1969—and the Office of Vehicle Safety, which remained in the old Industrial Building until it was transferred to the Department of Transportation in 1972.

A Symposium on Technology and World Trade was one of the events that took place during the dedication of the NBS Gaithersburg laboratories in November 1966. Vice President Hubert Humphrey addressed symposium attendees at a banquet held at the Department of State. Seated to the left of the dais was Professor Marshall McLuhan of the University of Toronto, well-known for his explorations of the relationship between technology and culture.

Organization and Staffing

In 1968, as Allen Astin prepared to hand over the directorship of NBS to his successor, he supervised a staff of over 3000 full-time employees, divided among the many scientific disciplines of the Bureau—in physics, chemistry, materials, mathematics, and engineering. The staff also included administrators, technicians, and clerical workers as well as other support personnel such as firefighters, police, a medical unit, and buildings-and-grounds workers. The most noticeable change in the composition of the Bureau staff during the previous 15 years had been the growth in the number of administrators, arising from increasing demands for planning and documentation.

The reader should recall that nearly all the staff and projects devoted more or less entirely to military work during World War II had been transferred as whole units to defense organizations by 1954, substantially reducing the size of the Bureau population from its previous high of nearly 4800. A further reduction occurred in 1965, when the entire Central Radio Propagation Laboratory—approximately 650 people—and a group of 15 staff members from the Sound Section were transferred from NBS to the

Medical staff serving the Bureau Gaithersburg site during the mid-1960s. Chief of the staff was physician George H. L. Dillard.

Environmental Science Services Administration (ESSA) in order to bring the Nation's predominantly environmental programs into a single agency. Renamed the Institute for Telecommunication Sciences and Aeronomy, the old CRPL joined the Weather Bureau and the Coast and Geodetic Survey to form ESSA. The CRPL staff continued to occupy their previous quarters until 1967, becoming temporary tenants of the Bureau. Thus departed from NBS the group that, more than any other, had precipitated the acquisition of its Boulder site.

A chart showing the numbers of people employed by the Bureau during its first 90 years of existence is presented in Appendix E. The influence of war work as well as other events that affected the level of NBS staffing show clearly in this graph.

The reassignment of so many staff members during the post-WWII period—nearly 40 percent of the Bureau's permanent force—was not seen by NBS management as a blow to its influence or importance. Instead there was a sense of refocusing of the efforts of the agency on its central mission of providing measurement standards and scientific and technical support for the needs of the Nation—leaner and cleaner, so to speak. Many projects remaining at NBS were related to the mission of the Defense Department and its contractors, but these now mainly took the form of solving scientific, technical, or metrological problems, not primarily the development of weapons hardware.

The pared-down (and partially rebuilt) permanent staff of NBS as of June 30, 1968, numbered 3,519, of which about one-third held academic degrees (509 physicists, 279 chemists, 261 engineers, 56 mathematicians, and 133 in assorted other disciplines). One-sixth of the permanent staff were located in the Boulder laboratories.[55]

Major Organizational Units

A hierarchy of three "institutes" was created by Allen Astin in 1964 in order to reduce the number of technical organizations reporting to the Director. Seventeen division chiefs had reported directly to Astin, but by 1968 the entire Bureau staff was represented by only five major organizational units.

The Institute for Basic Standards, placed under the leadership of Ernest Ambler, incorporated most of the old-line standards and calibration divisions in Gaithersburg, as well as all of the staff at the Boulder site.

The Institute for Materials Research, with John D. Hoffman as director, was composed of five materials-oriented divisions and the Office of Standard Reference Materials.

The Institute for Applied Technology, directed by Lawrence M. Kushner, comprised some 16 divisions whose activities ranged from computer science to engineering standards.

In 1968, the four NBS divisions concerned with the theory and application of ionizing radiation were formed into a Center for Radiation Research, with Carl O. Muehlhause as Acting Director. By 1971, the Center had been incorporated into the Institute for Basic Standards.

The Office of the Associate Director for Administration was supervised by Robert S. Walleigh. This group provided accounting, personnel, supply and other Bureau-wide services to the staff.

Nearly all of the permanent Bureau staff—and most of the part-timers—worked in one or another of these five major units.

The institute and center directors were "... responsible for the development and direction of research programs and central national services essential to the fulfillment of a broad segment of the Bureau's mission."[56] They also provided general supervision to the division chiefs, as well as guidance on overall space and financial matters. Although final Bureau management authority resided in the five units identified above, the division management level still provided the backbone of the Bureau's scientific

[55] *1968 Technical Highlights of the National Bureau of Standards: Annual Report, Fiscal Year 1968,* Natl. Bur. Stand. (U.S.) Special Publication 308, November 1968.

[56] *1964 Technical Highlights of the National Bureau of Standards: Annual Report, Fiscal Year 1964,* Natl. Bur. Stand. (U.S.) Miscellaneous Publication 264, December 1964.

and technical effort. Day-to-day direction of the staff, equipment and space needs of individual scientists, and the first level of personnel evaluation and counseling took place within the divisions.

"Matrix Management" Comes to the Bureau

Since 1904 the Bureau had utilized the principles of sharing project responsibility among its technical units. A major fire that year in Baltimore, followed by a smaller one on the grounds of NBS itself, showed an abysmal lack of standardization in the firefighting apparatus of the Nation.[57] Called upon to improve the situation, staff members throughout the Bureau contributed to the design of standard hose connectors and other equipment items and to the education of firefighters regarding their use. Because of the continuing national need for fire research, the fire program of the Bureau continued to flourish to the present day.

With the creation of programs in Standard Reference Data and Standard Reference Materials in the mid-1960s, cooperation across the boundaries of technical division lines became more formalized, leading to a new type of management. In both the SRD and the SRM programs, the managers directly supervised small staffs to "market the product"—standard data and standard samples, respectively. The actual generation of the "product" was mostly in the hands of scientists located elsewhere in the NBS organization or, occasionally, outside NBS altogether. Encouragement (and frequently, money) provided the incentive that caused the desired work to be accomplished.

The inauguration of an administration-wide initiative on *Program Planning and Budgeting* during Lyndon Johnson's presidency provided a surge of effort throughout the Federal government to understand and apply the idea of program-based management interlocking with a discipline-based staff.

The system whereby a given employee might owe allegiance to, say, the Analytical Chemistry Division and simultaneously participate as a member of a Standard Reference Data project came to be known as "matrix management." In one form or another it was in use for decades; during the 1960s and 1970s use of the name became more prevalent.[58]

To the analytical minds of NBS managers, the name matrix management was well-chosen because of its similarity to the mathematical matrix, which is composed of rows and columns. Individual rows of the management matrix, for example, might each denote a technical division within NBS and individual columns might define program responsibilities for particular members of that division. A given column could be identified, say, as the Office of Standard Reference Data; a checkmark at the intersection of the OSRD column and a particular division's row would indicate that one or more of the division staff contributed to the work of the OSRD, either "for free" or as a grantee. Such a matrix management diagram was useful mainly as a tracking device, showing the reach of particular programs across Bureau disciplinary lines.

[57] MFP, p. 82.

[58] See, for example, Kenneth Knight, editor, *Matrix Management* (New York: PBI-Petrocelli Books, 1977).

In most cases, the "program" or "office" involved in matrix management included no laboratory space, but only a responsibility to produce certain results on behalf of an outside organization or a congressional mandate. Sometimes "program" results were simply accounts of work done in pursuit of a division goal that happily fit into the program's objective. In other cases, the program manager, by the judicious insertion of money into one or more of the laboratory units, could focus a division's technical work on a desired program objective. This type of administrative work demanded a nice mix of technical ability and administrative cooperation.[59]

The Standard Reference Data program, under Edward Brady, and the Standard Reference Materials program, under W. Wayne Meinke, were two of the major managed programs at NBS in 1968. Many other such programs followed, as we shall see.

The matrix management system, whenever it involved funds from other government agencies or from organizations outside the government, could provide needed financial support beyond that available directly from the NBS congressional appropriation, and *ipso facto* could show the relevance of Bureau work to the collaborating organization. Both of these characteristics were good, but the level of such funding often was subject to change without notice, which was bad. Bureau managers were often hard-pressed to avoid staff disruption resulting from rapidly varying funding levels.

Equal Employment Opportunity

From earliest times, employment at NBS was not governed by distinctions based upon race, gender, or other incidentals. The natural tendency of Bureau technical managers was to hire the best person available for a given position so as to produce the best possible results. The unintended result of this tendency was to perpetuate the *status quo*. In 1964, passage of the Civil Rights Act, which mandated the formation of an Equal Employment Opportunity structure, impacted Bureau hiring policies as it did in nearly all Federal agencies.

The first formal steps toward an EEO structure were taken in 1965 by Director Allen Astin, with a plan for a two-person NBS Equal Employment Office and specific attention to the hiring, training, and promotion of minorities.[60] In 1968 Astin ordered the formation, within the Personnel Division, of an advisory committee to review progress in hiring minorities.[61] The committee, consisting of Donald G. Fletcher, Karl E. Bell, and Robert F. Bain, was to receive any complaints of incidents of discrimination occurring on the Bureau grounds.

[59] H. Steffen Peiser recalls a suggestion by Irl C. Schoonover, then Deputy Director of NBS, that the sole function of program managers be the awarding of funds, with no project management to be exercised.

[60] Memorandum to Secretary of Commerce John T. Connor from A.V. Astin, "NBS plan for expanding equal employment opportunities," December 15, 1965. (NIST RHA, Director's Office, Box 381, Folder Nov. 1–Dec. 31, 1965.)

[61] Memorandum from Director Astin to NBS Deputy Director; Associate Director for Administration; Institute Directors; Director, Center for Radiation Research; and Division Chiefs, "Reaffirmation of Equal Employment Opportunity Policy and Practices," May 16, 1968. (NIST RHA, Director's Office, Box 386, Folder Chrono File May 1–June 30 1968.)

In that same year, Astin and his peer at the National Institutes of Health, James A. Shannon, advised the Montgomery County, Maryland, County Council of their desire to see a positive stance on equal access to county housing. The Council quickly responded by enacting a Public Accommodations Ordinance forbidding discrimination in housing and public places. A Montgomery County Commission on Human Relations was created to deal with complaints of discrimination in the community.[62]

One of Astin's last acts as Director was to refine the Bureau's EEO system. The EEO Committee was expanded to nine members selected from divisions throughout NBS: Harvey E. McCoy, Nina Knight, and Charles W. Anderson (Administrative Services Division); Avery T. Horton (Inorganic Materials Division); Donald G. Fletcher (Product Evaluation Division); Jon T. Hougen (Atomic Physics Division); Elizabeth L. Tate (Library Division); Karl E. Bell (Personnel Division); and Joyce J. Grimes (Physical Chemistry Division).

At the same time, an Affirmative Action Plan was developed for the Bureau. This plan identified recruitment, training, publicity, and incentive awards as areas where NBS could improve its utilization of minority employees. In addition to the committee and the plan, a new Civil Service program for the resolution of grievances was adopted by the Bureau.[63]

Avery Horton, named Chairman of the EEO Committee, took his committee responsibilities seriously. A chemist with an active interest in the properties of crystals,[64] he nevertheless spent considerable time in an effort to ensure fair treatment for minorities, both in the Bureau and in the community. At one point, distressed by the refusal of a local barber to cut his hair, Horton filed and won a discrimination lawsuit against him. This suit helped to end the segregation of commercial public facilities in Montgomery County.[65]

Part-Time Employees, Guest Workers and Visitors

In addition to the full-time staff members at NBS in 1968, there were 353 part-time, summer,[66] Youth Opportunity Corps, intermittent, and temporary workers. In addition, 147 research associates and guest workers, including many from foreign countries, were part of the Bureau staff. The research associates represented 31 different organizations—trade associations and individual firms—whose activities involved measurements and standards at a level where they needed to have one or more people working at NBS.

[62] Memorandum to All Employees from A. V. Astin, "Equal Opportunity," July 12, 1968 (NIST RHA), Director's Office, Box 386, Folder Chrono File 7-1-68–8-31-68.

[63] "NBS Moves to Insure Equal Opportunity For All Employees," NBS Standard, June 1969, p 1.

[64] See, for example, R. Brooks, A. T. Horton, and J. L. Torgesen, "Occlusion of mother liquor in solution-growth crystals," *J. Crystal Growth 2*, pp. 279-283 (1968).

[65] Karl E. Bell recollects that Horton and the barber eventually became friendly to the extent that Horton, an amateur cabinetmaker, refurbished the man's barbershop.

[66] For a personal insight into the summer-student program, see "NBS Summer Programs," *NBS Standard*, Vol XV, No. 9, September, 1970, pp. 7-8.

The Bureau had actively welcomed visits from foreign scientists and engineers for many years. Most of these visitors came from other national standards laboratories or from international agencies with strong interests in standards, such as the International Bureau of Weights and Measures, the United Nations, the North Atlantic Treaty Organization, the International Atomic Energy Agency, and the International Standards Organization. Visitors from countries whose standards programs were still developing often came with the dual objectives of studying the NBS organization and management techniques and of participating in scientific projects; among other countries, Mexico, Iran, South Korea, Saudi Arabia, and Taiwan sent this type of visitor. Visitors from countries with advanced efforts in metrology usually came as full partners in continuing research programs. During 1968 some 700 foreign scientists visited NBS; 24 other foreign scientists representing 16 different countries had guest status.[67]

Post-Doctoral Research Associates

Included in the full-time-permanent category in 1968 were 42 postdoctoral research associates assigned to the Bureau through a joint program of the National Research Council, the National Academy of Sciences, and the National Academy of Engineering. In part, the selection process included approval by the potential mentor of a plan for a scientific or engineering project to be accomplished at NBS. Each of the successful candidates received an opportunity to work at NBS with a world leader in metrological science. But the Bureau received enormous benefits as well; the influx of vigorous young scientists, trained in up-to-the-minute scientific methods in the Nation's best graduate schools, brought a flood of new ideas and techniques that permeated the NBS laboratories. The program was important, too, because it provided an opportunity for NBS managers to appraise in detail the quality of potential future staff members.[68]

In the following paragraphs, we list the names of the 1968 postdoctoral associates, officially called "NRC-NBS Postdoctoral Research Associateships recommended by the NAS-NRC." We list as well their graduate schools and (in parentheses) their NBS mentors:

- Donald W. Alderman, Cornell University (Robert J. Mahler, head of solid state electronics in the Radio Standards Physics Division in Boulder).
- Michael J. Bielefeld, University of Pennsylvania (Jon J. Spijkerman, Analytical Chemistry Division).
- Edith F. Borie, University of North Carolina (Leonard C. Maximon, Radiation Theory group, Center for Radiation Research).

[67] Ronald B. Johnson, Executive Officer for the Institute for Materials Research during that period, kindly points out that the term "Guest Researchers" was much preferred by many visiting scientists over the less-elegant "Guest Worker" title commonly used in Bureau personnel reports.

[68] An informative account of the the origin and early history of the postdoctoral program at NBS is given by Joseph Hilsenrath, "The National Academy of Sciences-National Research Council's Postdoctoral Research Associateship Program," NBS/GCR-85/500, September 1985.

- Arnold M. Denenstein, University of Pennsylvania (Chester H. Page, chief of the Electricity Division).
- Gabriel L. Epstein, University of California, Berkeley (Joseph Reader, Atomic Physics Division).
- Benjamin Gibson, Stanford University (Michael Danos, Radiation Theory group, Center for Radiation Research).
- Roger A. Hegstrom, Harvard University (Jon H. Shirley, Time and Frequency Division, Boulder, and Richard P. Reed, Cryogenics Division, Boulder).
- John W. Knoeck, Iowa State University (John K. Taylor, head of microchemical analysis in the Analytical Chemistry Division).
- Hassell M. Ledbetter, University of Illinois (Richard P. Reed, Cryogenics Division, Boulder).
- William R. Ott, University of Pittsburgh (Wolfgang L. Wiese, head of plasma spectroscopy in the Atomic Physics Division).
- Stephen J. Pierce, University of California, Santa Barbara (Morris Newman, head of numerical analysis in the Applied Mathematics Division).
- LeRoy W. Schroeder, Northwestern University (John J. Rush, Reactor Radiation Division).
- Stuart K. Searles, University of Alberta, Canada (Pierre J. Ausloos, head of radiation chemistry in the Physical Chemistry Division).
- Stanley E. Stokowski, Stanford University (Ludwig H. Grabner, Inorganic Materials Division).
- Donald D. Thornton, Syracuse University (Billy W. Mangum, Heat Division).
- Edward F. Zalewski, University of Chicago (Richard A. Keller, Physical Chemistry Division).

Of the 1968 postdoctoral group, Ledbetter, Ott, Schroeder, and Zalewski (one-fourth of the group) became permanent Bureau researchers.

From the beginning of the postdoctoral program in 1955 until 1969 there were a total of 173 of these awards. Alumni of the program were prominent among NBS leaders in scientific and management programs at NBS. Names of subsequent postdoctoral research associates are listed in Appendix F.

Professional Advancement, Education, and Awards

From the time of its move to Connecticut Avenue, NBS possessed some of the characteristics of a technical university. Many Bureau scientists and engineers were motivated to give extra effort as much by the desire to learn as by the desire to take home an extra-large paycheck. In areas of front-line research, NBS staff members and their university colleagues enjoyed very close professional relationships, belonging to the same organizations, attending the same conferences, publishing in the same journals and competing for the same types of professional recognition. In addition, there was a steady flow of teacher-student interactions among the technical staff of the Bureau, both in Boulder and Gaithersburg.

In 1968, the NBS Graduate School program was already in its 60th year; four new diplomas were added that year to the 344 graduate degrees awarded to Bureau staff members since its inception.[69]

Staff development was not limited to graduate-level training, however. Educational programs were also in place for more than 600 undergraduates, technicians, secretaries, and other non-technical staff, fulfilling the twin goals of keeping up with current technology and providing Bureau employees with an avenue for personal advancement. Instruction, often by outside consultants, was available both on-site and in conjunction with local schools, not only for the Gaithersburg facility but also for Boulder personnel.

Most of the technical divisions scheduled periodic seminars, colloquia, or staff meetings—often on a weekly basis—on subjects related to division projects. These technical meetings, held in small conference rooms maintained in the Administration building and in each of the technical buildings, generally were led by local staff or by visiting experts. Advertised on local technical bulletin boards, they usually attracted interested participants from outside the Bureau—other government scientists, professors from area universities, visitors from far-off places, and, increasingly, personnel from small-scale, high-technology industries developing on the "doorstep" of NBS.

Technical meetings provided a good mechanism whereby new projects could be explored, current ones could be exposed to scrutiny by peers, and completed work could be publicized. In addition, frequent lectures were offered in the major auditoriums. The "Red" auditorium, seating about 700, and the "Green" auditorium, seating about half that number, were the largest Gaithersburg halls, while the Radio Building Auditorium hosted the largest meetings at the Boulder site. These lectures provided large technical audiences—from NBS and elsewhere—with talks of general interest.

High-quality work by the staff of the NBS was recognized every year by awards from outside groups, from the Federal government and from the Bureau itself. More than 30 NBS staff members were recognized in 1968 by external professional groups, including the following:

- Samuel N. Alexander, the Harry Good Memorial Award of the American Federation of Information Processing Societies.
- Melvin R. Meyerson, the George Kimball Burgess Award of the Washington Section of the American Society for Metals.
- Robert D. Stiehler, Award of Merit of the American Society for Testing and Materials.

[69] *1968 Technical Highlights of the National Bureau of Standards: Annual Report, Fiscal Year 1968,* NBS Special Publication 308, November 1968.

- Allen V. Astin, the Commendation Plaque of the National Conference on Weights and Measures, and the Distinguished Alumni Award of the University of Utah Alumni Association.
- F. Cecil Brenner, the Notable Services Award of the Apparel Research Foundation.
- Lewis M. Branscomb, the Career Service Award of the National Civil Service League.
- Robert D. Cutkosky, the Scientific Achievement Award of the Washington Academy of Sciences.
- Jon T. Hougen, the Coblentz Society Award.
- Malcolm W. Jensen, the Commendation Plaque of the National Conference on Weights and Measures.
- W. Wayne Meinke, the American Nuclear Society 1968 Special Award for Industrial Applications of Radiation Techniques.
- Morgan L. Williams, the Bissell Award of the Washington Section of the American Welding Society.

In 1968 the Department of Commerce honored eight Bureau staff members with the Department of Commerce Exceptional Service Award (the "Gold Medal"). Those honored were:

- Louis Costrell, for radiation physics instrumentation.
- Henry J. Kostkowski, for radiation thermometry.
- Lawrence M. Kushner, for research management.
- David R. Lide, Jr., for molecular structure studies.
- Kurt E. Shuler, for chemical physics.
- Carl O. Muehlhause, Harry H. Landon, Jr., and Robert S. Carter, a group award for nuclear radiation research.

The Department of Commerce also awarded silver medals for Meritorious Service to:

- David W. Allan, for atomic frequency and time standards.
- Clarence N. Coates, Jr., for legislative programs.
- William C. Cullen, for materials durability studies.
- John R. Cuthill, for alloy physics.
- James R. DeVoe, for radiochemical analysis techniques.
- Samuel B. Garfinkel, for radioactivity standards.
- Kurt F. J. Heinrich, for x-ray spectrometry.

- Frank L. McCrackin, for ellipsometry studies.
- Harvey Marshak, for low-temperature nuclear orientation.
- William C. Martin, Jr., for atomic spectroscopy.
- Hans J. Oser, for studies in systems dynamics.
- James F. Schooley, for superconductivity.
- W. Reeves Tilley, for technical communication.
- William W. Walton, for building research.
- Andrew W. Weiss, for plasma spectroscopy.
- Harold F. Wollin, for weights and measures.
- William R. Shields and Thomas J. Murphy, a group award for studies in analytical mass spectrometry.

Department of Commerce Superior Service (Bronze Medal) Awards went to 12 Bureau members:

- Richard M. David, for radiation chemistry.
- Herbert H. Garing, for instrument construction.
- Elizabeth L. M. Henley, for administrative systems.
- Albert E. Ledford, Jr., for molecular energy level work.
- Katherine S. Lunsford and Minnie R. Massie, a group award for thermometry calibration.
- Cornelius H. Pearson, for thermophysical properties.
- Ruth L. Peterson, for spectroscopy.
- Marion S. Roberts, for employee development techniques.
- Wilbert F. Snyder, for radio standards engineering.
- Earl S. Williams, for electrical instrumentation.

The Bureau itself that year presented the Eugene C. Crittenden Award to eight staff members for superior performance by support personnel:

- James Hester, for electrical services.
- John Hydro, Jr., for glassblowing.
- Harman L. Lantz, for floor care.
- Grace S. Lederer, for procurement services.
- Susan B. Mayers, for cleaning services.
- John L. Michalak, for structural testing.
- Arthur Pittman, Jr., for payroll services.
- Lawrence Schneider, for precision instruments.

The 1968 NBS Samuel Wesley Stratton Award was given to David R. Lide, Jr. for his outstanding work in the field of microwave spectroscopy.

The Edward Bennett Rosa Award, recognizing outstanding achievement in the development of standards of practice in the measurement area, was presented to W. Wayne Meinke for his efforts with the Standard Reference Materials program.

In Appendix G we list the recipients of major awards given from 1968-1993 by the Department of Commerce and by NBS/NIST.

Cash awards, grade-level promotions or certificates for outstanding work were presented to other high-achieving employees by most NBS divisions.

Mens Sana in Corpore Sano

The history of recreational activities at the Bureau has long been closely intertwined with the history of the Standards Employees Benefit Association (SEBA). Perhaps the first participation in organized sports at NBS was the Interdepartmental Tennis League; tennis teams from the Bureau competed with other agency teams as early as the 1920s. Eventually, SEBA sponsored many intramural activities for Gaithersburg employees, including the following:

- Chorus.
- Slow-pitch softball.
- Fast-pitch softball.
- Women's softball.
- Football.
- Golf.
- Tennis.
- Basketball.
- Bowling.

The Gaithersburg site also saw considerable noon-time and after-hours intramural and extramural athletics, including volleyball, basketball, softball, bicycling, and jogging.

Recreational activities for the Boulder employees of NBS were substantially less well-organized, but no less enthusiastic. The Boulder Laboratories Employee Association (BLEA) occasionally sponsored picnics, softball, and other group events; however, most sports and other hobbies were organized informally.

According to the recollection of Robert A. Kamper, cycling, running, hiking, fishing, rock and mountain climbing, and skiing in the nearby mountains attracted many of the Boulder staff. It was not unusual for Bureau individuals or groups to "take to the hills" for a day's recreation in any manner favored by the weather. Kamper also recalled a period of time during the early 1970s when musicians from the Bureau joined in annual treks up the mountain with symphonic instruments to perform in the Altissimo Music Festival—a fine combination of art and athletics.

During the early 1990s, James D. Siegwarth and B. James Filla, assisting paleontologist Robert Bakker in his search for the remains of dinosaurs, discovered a previously unknown species. Professor Bakker named the species Nisti, in honor of his volunteer colleagues, thus gaining for the Boulder laboratory the distinction of being the only Federal agency with a dinosaur named for it.

Advisory Committees

Following the practice introduced at its founding (Sect. 1.3), NBS programs and equipment were monitored annually by a Visiting Committee of outside technical experts appointed by the Secretary of Commerce. The Secretary often sought the advice of the senior Bureau management on new appointments to the Visiting Committee. Over the years, the Visiting Committee was a strong advocate for the NBS/NIST programs as well as a critical observer of the state of Bureau facilities, equipment, and output. Its reports offered strong encouragement to the Department to shore up weaknesses or to enter new areas of research. The membership of this important group is given in Appendix H.

In 1968 the Visiting Committee was chaired by Robert Sproull, Vice President of the University of Rochester. Other members of the committee included Norman Ramsey, Professor of physics at Harvard University; Emanuel R. Piore, Vice President and Chief Scientist of IBM Corp; Elmer W. Engstrom, President of RCA; and Paul C. Cross, President of the Mellon Institute.

In addition to the NBS Visiting Committee, technical evaluation panels annually reviewed the work of many technical divisions of NBS from 1959. The President of the National Academy of Sciences appointed members of the panels that advised the divisions of the Bureau's Institute for Materials Research and the Institute for Basic Standards. Similarly, the President of the National Academy of Engineering appointed panels for the divisions of the Institute for Applied Technology. The committees prepared formal reports for the use of the National Research Council, but perhaps more important was the guidance that they gave informally to the division leadership.

Budget

The NBS budget often resembled the heroine in the serial thriller "The Perils of Pauline." The draft of the budget document, with its carefully drawn plans and requests for their support, lurched from crisis to crisis, with painful injury or death imminent from moment to moment. This resemblance was particularly apt in 1968, when Congressman John J. Rooney of New York served as Chairman of the Subcommittee on Departments of State, Justice, and Commerce, The Judiciary, and Related Agencies Appropriations, a unit of the House Committee on Appropriations. Mr. Rooney's subcommittee held annual hearings on the NBS budget, and there was no doubt who was in charge. For the entire duration of his chairmanship, 1963 to 1974, the appropriations hearings featured a running Rooney-against-the-bureaucrats sideshow that makes fascinating reading but could only have been a nightmare for NBS management.[70]

[70] The text of the hearings is contained in bound records published by the U.S. Government Printing Office.

The difficulties that NBS encountered in balancing its commitments against its budget, like the budgetary problems of many another federal agency, arose from the dichotomy that is characteristic of the U.S. Congress: Congressional authorization *vs* Congressional appropriation.

Continuing oversight of NBS programs resided in 1968 in the House Committee on Science and Astronautics and its Subcommittee on Science, Research, and Development, along with its Senate counterpart, the Senate Commerce Committee and its Subcommittee on Science and Technology. Most of the assignments given to the Bureau by Congress originated in these subcommittees, whose members were generally familiar with its staff and the capabilities of the agency. The members of these subcommittees were, in general, supportive of NBS. They felt that the Bureau gave good value for the Congressional dollar, and they were willing to entrust new projects to it through the authorization process.

Once a particular project was outlined by the authorizing committees for NBS, however, the House Appropriations Committee could decide whether the proposed project was worthy of funding to pay for personnel, facilities, and operations needed to execute it. The wherewithal to perform either existing or new projects at the Bureau necessarily came from the House Committee on Appropriations, Subcommittee on Departments of State, Justice, and Commerce. Not infrequently, the authorizing committee and the appropriations committee did not see eye to eye on the necessity of a given task or on the suitability of NBS to perform it, let alone its proper funding level. Thence came trouble, with the Bureau cast in the hapless role of the shuttlecock in a game of Congressional badminton.

A typical NBS budget document began life at least one year before funds were expected from it. Its beginning was generally peaceful and straightforward, as befitted the nature of its scientific authors: plans were laid for continuing and new projects, based upon technological needs or scientific opportunities as foreseen by NBS in consultation with the Congressional oversight committee; justifications were written for any foreseeable changes necessary in Bureau space, personnel, or operational costs to accomplish them; and prospective sources were identified for funding—typically Congressional appropriations, other Federal agency funds, calibration fees, or sales of standard reference materials.

Aggregation of these ideas from throughout the Bureau resulted in the preparation of the first draft of a budget document. The document generally incorporated requests arising from arcane scientific projects—in 1968, such a project involved collecting data on the energy content and behavior of nuclear particles—side by side with requests arising from the most practical technical needs, exemplified in 1968 by NBS participation in technical committees of the American Standards Association.[71]

The basic budget document then entered the first phase of its perilous journey to reality—examination by the Department of Commerce, where fiscal and political pressures of a type unknown within NBS made all the difference. Endowed with different

[71] Now known as the American National Standards Institute.

viewpoints, with substantially different training, and with stimuli markedly different from those felt by the originators of the budget draft, the DoC examiners typically added to and subtracted from the document until it reflected an entity that they could vigorously defend in the dangerous second phase—review by the Bureau of the Budget (later known as the Office of Management and Budget).

In the BoB review, other pressures—frequently a desire to restrain spending throughout the Executive Branch—and different politics came into play, resulting in a new draft that all too often only vaguely resembled the original budget document. On the bright side, this budget, once prepared, generally was supported by *the President of the United States.*

The greatest peril to the document usually—but by no means always—occurred during the hearings of the House Appropriations subcommittee that enjoyed jurisdiction over the Bureau's finances. The scientific content of the budget draft often faded into insignificance in comparison with wrangling over issues totally unrelated to NBS activities. Logic became twisted or, not infrequently, abandoned completely. Political motives usually dictated the fate of portions of the document. In the meantime, other Federal agencies were learning of their own budgetary destinies, which in turn might determine whether they could participate financially in planned cooperative projects with NBS staff members.

Finally, a joint conference of House and Senate members could further adjust the NBS budget. The result of this lengthy process was that the President often signed a budget document for the Bureau that was barely recognizable as the offspring of the original draft.

Not uncommon was a disappointing situation wherein no budget at all was passed, months after the beginning of a new fiscal year. In these cases the process had broken down, with Congress so involved with other activities that it did not complete one of its most basic tasks. The usual solution in that case was known as a "Continuing Resolution," which could be translated roughly by the instruction "Do what you did last year at the same (or a lower) level of spending."[72] In this event, of course, the NBS leadership had to make educated guesses as to what should be done about very desirable new projects or tasks that Congress had ordered NBS to perform. During "continuing resolution" years, Congressionally requested projects usually were undertaken by reassigning existing staff, space and equipment. New projects proposed by NBS usually were deferred.

During any budget cycle, it was not unusual for a congressional authorizing committee to formally ask ("mandate") the Bureau to perform specific tasks that one or another member deemed desirable at the time.[73] Sometimes the instructions for the

[72] Poor as it was, the continuing-resolution option was preferable to the alternative—temporarily closing the doors of NBS for want of authorization to continue operations.

[73] The Congressional request might have been made of the Secretary of Commerce, asking him to utilize his "scientific resources" for a particular task, an instruction that often resulted in an assignment for NBS.

assigned tasks were included in legislation that was not part of the appropriations process; such legislation may or may not have authorized reimbursement to the Bureau for the costs involved in fulfilling the requested work. Any such "unfunded mandates" usually caused the Bureau management to generate staff, space, and funds for the work by deferring or abandoning other work. Congressionally mandated work at NBS in 1968 included the following:

- In December 1967 the 90th Congress amended Public Law 88-164 (15 U.S.C. 1191; 67 Stat 111), originally passed on June 30, 1953, and known as the *"Flammable Fabrics Act."* The amendment, PL 90-189 (81 Stat 568), authorized the Secretary of Commerce (and thus NBS) to (1) conduct research into the flammability of products, fabrics, and materials; (2) conduct feasibility studies on the reduction of flammability in such items; (3) develop flammability test methods; and (4) offer training on flammability issues. The Act authorized $1.5 million to pay the costs of all its provisions during FY 1968, with $2.25 million authorized in each of the following two years.

- The *Fire Research and Safety Act* of 1968 (PL 90-259, 82 Stat 34, passed in January 1968) amended the Organic Act of NBS to authorize the Bureau to undertake a wide-ranging program in fire research and information dissemination. It authorized $5 million in funding through June 30, 1970.

- The *Standard Reference Data Act* of 1968 (PL 90-396, 82 Stat 339, passed on July 11, 1968) gave the Secretary of Commerce authorization for the "... collection, compilation, critical evaluation, publication, and sale of standard reference data." The sum of $1.86 million was authorized for expenditure on this task through June 30, 1969. Authorization also was given for the recovery of costs through sales of data. The Bureau was permitted to copyright data publications as well; this privilege was unique among Federal agencies. The provisions of this act enlarged and formalized an activity that had been under way for many years in conjunction with the Nation's chemistry, physics, and engineering communities, the Federal Council for Science and Technology, and the President's Science Advisory Committee.[74]

The overall financial support of NBS in 1968 amounted to slightly over $65 million. Of this amount, almost $33 million was appropriated by Congress to fund Bureau operating programs; this sum was augmented by $28.4 million received for work done on behalf of other Federal agencies, for other outside groups, or as payment for calibrations, standard reference materials, or other services. Congress also provided nearly $4 million to be used for plant and facilities support and for new construction.[75] In Appendix I we provide a chronological display of the regular congressional and

[74] The acts containing these mandates are recorded in Appendix A.

[75] *Annual Report for 1968* (NBS Special Publication 308, November 1968) p. 162.

special appropriations for NBS/NIST as well as funds provided by other government agencies for the period 1968-1993.

One can only hope that the eventual funding level of Bureau requests for support from Congress rested upon firmer ground than is indicated by the 1968 hearings of Congressman Rooney's subcommittee.[76] Mr. Rooney routinely reacted to the very detailed, heavily justified budget request of Director Astin as if Astin were part of a conspiracy to raid the U.S. Treasury for nefarious purposes. Perhaps more aggravating, in frequent side comments Rooney seemed at pains to denigrate the highly trained scientific staff of the Bureau. It has been said that Rooney's comments were intended to portray for his constituents an image of fiscal responsibility on the part of one who controls public purse strings. Nevertheless, one finds these congressional barbs disturbing—in part because they took place in a "game" in which only one team was allowed to "play," but also because of the possibility of real damage to the Nation's scientific enterprise under the pretext of fiscal responsibility.

Publications By NBS Staff

It can be argued that the most important output of many an NBS scientific project was a number—the quantitative result of a careful measurement, expressed in the appropriate unit. The number might describe the frequency of an atomic transition, the temperature of a phase transition, the spacing of a crystalline lattice, or the breaking-strength of an aerospace material, to be compared with measurements made in a similar project elsewhere or to be used in defining a new standard of measurement.

However, the national technical community probably valued most highly—perhaps more than NBS calibration results, *Standard Reference Materials,* or service on technical committees—the publications that described Bureau work. Even when a long-awaited number such as those mentioned above had been communicated by the quickest means available, its significance had to be documented by a carefully recorded exposition of the experimental techniques that produced it, along with its uncertainty. The intention of most Bureau publications was to provide information of such quality that the results described therein could be duplicated elsewhere even if the originating laboratory was destroyed or abandoned. The aim of the Bureau was to make these publications as widely available as the technical public desired.

In 1968 the NBS staff published its scientific and technical results in many different outlets. The effort to communicate the results of the Bureau's research, development, and service work was a vigorous one, producing as many as 1000 items each year. Titles of most of these publications were printed in the *NBS Annual Report* series, prepared for the use of the NBS Visiting Committee and for distribution to the Department of Commerce and other interested parties. Abstracts of publications originating

[76] Hearings Before a Subcommittee, 90th Congress, First Session, Part 3, Department of Commerce.

in 1968-69 were printed in *NBS Special Publication 305, Supplement 1,* issued under the editorial leadership of Betty L. Oberholtzer in December 1970.[77] This series was continued through 1997 with annual or biennial supplements.

Individuals who wished to consult Bureau publications generally had two options: they could subscribe to any of the Bureau periodicals or purchase, from the Government Printing Office, copies of listed Bureau publications; or they could visit one of the many technical libraries that possessed the publications and consult them there. Besides libraries in large cities and at educational institutions, a class of "Depository Libraries" in various states and U.S. possessions routinely received and stored NBS publications. This large network of outlets made the results of Bureau projects available on a wide basis indeed.

Editorial Review

The mechanism for oversight of Bureau publications was modified by Director Astin in 1965. Responsibility for enforcing Bureau policies in its publications was transferred to the Associate Director for Technical Support. Technical review of NBS publications resided in the Washington Editorial Review Board (WERB), which was the oldest committee at the Bureau,[78] and in three Boulder Editorial Review Boards representing the Central Radio Propagation Laboratory; the Radio Standards Laboratory and the Cryogenics Division; and the Laboratory Astrophysics Division.[79]

All publications written by NBS staff members and any publications to be printed on the authority of NBS were reviewed by one or more peers of the author. The usual process involved an *Editorial Record* form which accompanied each manuscript on its way to becoming an NBS publication. The administrative superior of the author was expected to review the draft, often with the assistance of a colleague in the originating

[77] The last comprehensive record of NBS staff publications—referencing all the publications since its founding—was prepared while Edward Condon was the director. NBS Circular 460, published in August 1948, contained a listing of Bureau publications from 1901 to June 30, 1947. Papers published before 1942 were listed by title only; later entries included abstracts.

A supplement to Circular 460 was printed in May 1958—it updated the earlier document with abstracts of papers published from July 1947 through June 1957.

In April 1961 Betty L. Arnold of the Office of Technical Information and Publications edited Miscellaneous Publication 240, "Publications of the National Bureau of Standards, July 1, 1957 to June 30, 1960." For the first time, titles of articles written by NBS staff members for publication in outside journals were included in the listing.

A supplement to MP 240 prepared by Betty L. (Arnold) Oberholtzer was issued in April 1967. It contained abstracts of in-house publications from July 1960 through June 1966 and titles of outside publications from 1960-65.

The Special Publication 305 series was commenced in April 1969, again prepared by Oberholtzer. The initial volume covered the period 1966-67.

As this history was written, the NIST administration contemplated discontinuing the paper catalog in favor of a computerized "on-line" edition.

[78] Personal recollection of W. Reeves Tilley, former chief of the Office of Technical Information and Publications.

[79] Although each of the institute directors was given the authority to create its own editorial review board by NBS Administrative Bulletin 65-24 (superseding NBS Admin. Bull. 63-3), the Washington directors decided to create a single Washington Editorial Review Board with membership from each of the institutes.

section. The chief of the author's division supervised a separate review before sending the approved manuscript to the appropriate ERB for final review and disposition (except that the Laboratory Astrophysics Division ERB conducted its own final review). Occasionally the process was truncated if a particular lower-level reviewer was known to be especially knowledgeable on the topic and thorough in reviewing. The ERB final reviewer, besides judging the technical merit of the draft, also sought to ascertain that no Bureau policies would be violated by the publication.

The Bureau review and publication procedures appeared cumbersome and, to some, even paranoid. However, they served to keep the technical and editorial levels of NBS publications as high as the levels anywhere in science; editors of periodicals, conference proceedings, and books found few outright errors, half-digested ideas, or ambiguous expressions in Bureau writing. The members of the ERBs were among the most experienced of Bureau scientists, whose recommendations could not be taken lightly.

In 1965, the Chairman of WERB was Chester H. Page. Other members were Roger G. Bates, Randall S. Caswell, Vernon Dibeler, Myron G. Domsitz, Churchill Eisenhart, D. McIntyre, Robert D. Elbourn, W. Reeves Tilley, and John E. Carpenter. Carpenter served as Secretary to the Board.

The Chairman of the Central Radio Propagation Laboratory ERB was Douglas D. Crombie. J. Krantz was the Secretary. The membership included Edwin L. Crow, Kenneth Davies, Martin T. Decker, Mark T. Ma, George C. Reid, D.V. Row, James R. Wait, and Bernard Wieder.

David M. Kerns chaired the Radio Standards Laboratory ERB. Members included Vincent D. Arp, Edwin L. Crow, Glenn F. Engen, Thomas N. Gautier Jr., Richard C. Mockler, Robert C. Powell, Balfour B. Stewart, and Robert W. Zimmerer. Ms. Krantz was the Secretary of this board also.

The three-person Laboratory Astrophysics Division ERB was headed by Lewis Branscomb. Peter L. Bender and Sidney Geltman served as members.

By 1968, the Central Radio Propagation Laboratory was no longer part of NBS, having been assigned to the Environmental Science Services Administration. NBS/JILA papers were then monitored by the Laboratory Astrophysics Division ERB, and the Radio Standards Laboratory ERB reviewed all other papers originating in NBS/Boulder.

In 1969 Edward Brady was appointed Chairman of WERB. When asked in 1987 about the usefulness of the ERB system, Brady said:

> I think [the NBS Editorial Review Board] is enormously valuable to the Bureau. To have a peer review inside the Bureau before anything goes out adds another level of technical quality control that has been exceedingly helpful in guaranteeing that the material put out by the Bureau is high quality and not something foolish or something incorrect.[80]

[80] Edward L. Brady, Oral History, August 17, 1987.

NBS Journal of Research

The premier NBS technical periodical in 1968 was the *Journal of Research of the National Bureau of Standards.* It was issued in three parts. *Section A, Physics and Chemistry,* edited by Charles W. Beckett with assistance from Donald D. Wagman and John M. Richardson, was issued bimonthly. *Section B, Mathematical Sciences,* edited by Morris Newman with assistance from Frank W. Olver and John R. Edmonds, and *Section C, Engineering and Instrumentation,* edited by Martin Greenspan with the assistance of G. Franklin Montgomery, R.V. Smith, and A.F. Schmidt, were issued quarterly. Typically, archival descriptions of completed projects, with extended discussions of equipment, procedures, analytical techniques, and significance of the results in the respective fields, made up the majority of papers published in the *Journal of Research.*

Technical News Bulletin

Information concerning Bureau activities in research, development, cooperative projects with other scientific or technical groups, and publication notes was available during 1968 in the *Technical News Bulletin* (TNB). Feature articles in this periodical were selected from a *Summary Technical News Service* prepared specifically for the editors of hundreds of scientific, technical, and trade magazines.[81] They provided information on both the technical nature of the work and its relevance to the public at large.

The TNB was intended for industrial readers working in strongly technical areas. In 1968 this periodical was issued monthly. The Editor was W. Reeves Tilley. William K. Gautier was the Technical Editor, the Managing Editor was Richard W. Seward, and Carla Messina was the Visual Editor.

The January 1968 issue of the TNB, a fairly typical example, contained short articles describing fire safety studies of apartments, the results of an investigation into static fatigue of glass, and the properties of slush hydrogen that were of particular importance to the aerospace industry. It also contained notes on coming technical conferences and a report on the 13th General Conference on Weights and Measures. Other features included standards and calibration news, developments in the National Standard Reference Data and Standard Reference Materials programs, and titles of new NBS publications.

During 1973, Director Richard W. Roberts "restructured" the *Technical News Bulletin,* converting it to a "public relations" document with a new name: *"Dimensions."*

[81] The *Summary Technical News Service* articles were synopses of NBS archival papers. They were prepared in the Office of Technical Information and Publication by physical science editors Sharon L. Butrymowicz, Robert T. Cook, Donal K. Coyle, Jack R. Craddock, Carol R. Naas, Arthur Schach, and Don E. Webb. Circulation of the articles greatly increased public understanding of the work of the Bureau.

Non-Periodical NBS Publications

The Bureau offered nine non-periodical publication outlets in 1968. These outlets and the types of communication intended for publication therein were:

- *NBS Monographs,* " . . . major contributions to the technical literature on various subjects . . . ";
- *NBS Handbooks,* " . . . recommended codes of engineering and industrial practice developed in cooperation with interested industries, professional organizations, and regulatory bodies";
- *NBS Special Publications,* " . . . proceedings of . . . national and international conferences sponsored by NBS, precision measurement and calibration volumes, NBS Research Highlights . . . ";
- *NBS Applied Mathematics Series,* " . . . mathematical tables, manuals, and studies";
- *National Standard Reference Data Series,* " . . . quantitative data on the physical and chemical properties of materials . . . ";
- *NBS Building Science Series,* " . . . research results, test methods, and performance criteria . . . ";
- *NBS Technical Notes,* " . . . communications and reports of limited or transitory interest. Often . . . final reports of work sponsored at NBS by other Government agencies";
- *NBS Product Standards,* " . . . developed cooperatively with interested Government and industry groups, and used voluntarily"; and
- *Federal Information Processing Standards Publications (FIPS),* " . . . the official source of information in the Federal Government regarding (1) uniform Federal information processing standards . . . and (2) data elements and codes standards in data systems . . . "

Publication in Non-NBS Media

Although NBS publications clearly offered a multitude of avenues for the promulgation of results of work by Bureau staff members, there were excellent reasons for publishing certain results in outside journals, in books, or—on rare occasions—in newspapers.

The most cogent reason for publication in an "outside" venue was the desire to reach a specific audience as directly as possible. Thus a discussion of "Tests of the Born approximations: differential and total 2^3S, 2^1P, and 2^1S cross sections for excitation of He by 100 eV to 400 eV electrons," by John Arol Simpson and Stanley R. Mielczarek of the Atomic Physics Division and their colleague L. Vriens, a guest worker from the University of Utrecht in The Netherlands, was published in the journal *Physical Review* because that journal provided a principal forum for atomic physics topics. Similarly, Ernest E. Hughes' description of a simple method for the determination of the absolute concentration of oxygen in the atmosphere was published in the journal *Environmental Science and Technology* in order to reach a high percentage of the environmental scientists who might find such measurements helpful. And a 50-page study of the smoke and gases produced in the burning of materials typically used in aircraft interiors, performed by Daniel Gross, Joseph J. Loftus, Thomas G. Lee, and Vannie E. Gray of the Building Research Division, was published as an individual monograph by the Federal Aviation Agency to expeditiously bring the work to the attention of the air-transportation community.

Conference proceedings, specialized books or book chapters, and voluntary standards publications also were frequent vehicles for the scientific exposition of NBS authors who wanted to reach specific audiences.

In many cases, material written by Bureau authors was requested by outside groups who wished to make use of the expertise of particular NBS staff members. Textbooks, technical encyclopedias, instructional literature, and data compilations—all of these coaxed NBS writing away from NBS-based publications.

Not infrequently, questions of scientific priority led Bureau authors to publish their findings in journals that specialized in rapid communication. *Physical Review Letters, Chemical Physics Letters,* and Nature were examples of such journals. In Appendix J we provide a comprehensive listing of the publications of NBS and NIST.

NBS Technical Work in 1968

The quality of the National Bureau of Standards as an effective technical agency can best be judged by the range and significance of its scientific and engineering work. Here the historian's problem is an oversupply of the fabulous. Development and calibration of ingenious and wonderfully capable tools and standards for measurement; study of light from the stars; heat from the earth; water from ancient ice; transportation; communication; manufacturing; sales; medicine; agriculture; and space travel—all these activities and many others engaged the inquiring minds of NBS scientists and engineers over the years. The challenge for the historian is not that of finding fascinating topics to illustrate the significance of Bureau work, but to refrain from creating an indigestible catalog of scientific and technological exploits.

In the following sections we take a whirlwind tour through the Bureau's technical divisions as they were constituted in 1968. This tour provides an identity for each division, illustrating the type of work in which it was engaged as Director Allen Astin left NBS. The discussion also is meant to help the reader follow the relevance and origins of technical work that will be described in subsequent chapters.[82]

[82] Most of the information given here was obtained from the NBS Annual Reports, from material provided to the Senate Committee on Commerce at the time of its hearings on the nomination of Lewis Branscomb as NBS Director (Senate Committee on Commerce, *Nominations–1969: Hearings before the Committee on Commerce,* 91st Cong., 1st Sess., Dr. Lewis M. Branscomb, 31 July 1969: pp. 86-93), or from publication records of the period 1965-68.

In 1968, Bureau projects exhibited variety not only in the breadth of the their science and engineering, but in the composition of the work groups that produced them. In many—perhaps most—cases, a project was in the hands of one or two people who patiently pursued a technical goal, sometimes over a period of many years. Other efforts were undertaken by small groups of scientists or engineers, frequently assisted by one or more technicians. A few projects involved large numbers of NBS staff members, sometimes coordinating massive efforts with colleagues scattered throughout the world. Part of the unique nature of the institution resided in the flexibility of its approach to its tasks.

NBS Organizational Charts

There may not exist a governmental agency that does not circulate—at least among its own staff—an *Organizational Chart* showing the relationships that connect its component groups. It is only natural that this should be so, since the chart quickly establishes relative rank and helps to identify responsibilities within the agency. Yet the information conveyed by an organizational chart generally is of the most rudimentary kind—little of the depth of the agency's activities is to be found within a given entry. And seldom is an inkling given of the number of staff members represented by the listed organizational units.

NBS was always a dynamic entity—the more so during times of major change, when whole groups joined or disappeared from the agency. An updated organizational chart was issued at least twice a year, almost always with some changes from the previous edition.

For our technical tour of the Bureau, we utilize the chart issued on June 14, 1968, only months before Allen Astin retired. We here identify only a skeletal portion—approximately 60 organizational units including the division level—of the more complete listing given in Appendix K.

In Appendix K we also provide a chronological progression of the evolving NBS/NIST through 1991 as portrayed by its changing organizational charts.

Office of the Director (Allen V. Astin, Director, NBS).

The Director was responsible for the policies of the Bureau and for the development and execution of its programs. Besides the Deputy Director, Irl C. Schoonover, several other individuals reported directly to Astin. These included an assistant for metric study, Alvin G. McNish; a legal advisor, Allen J. Farrar; a senior research fellow, Churchill Eisenhart; and the heads of the following offices:

Office of Industrial Services (George S. Gordon, Chief).

The OIS examined the need for joint industry-NBS research activities; recommended methods by which NBS research results could best be utilized in industry and commerce; promoted cooperative research with industry for the solution of technical problems; and maintained the Research Associate Program.

The Research Associate Program was by then a 50-year-old Bureau activity. In 1968 it included 61 scientists and engineers. These visitors worked on a full-time basis at NBS on projects of mutual interest to their own organizations—industrial corporations, technical trade associations, professional societies, and other Federal agencies—and the Bureau. The salaries of Research Associates were paid by the sponsoring organizations. The OIS performed an outreach function to encourage and facilitate participation in the program, providing industrial groups with information about NBS and its projects.

Office of Engineering Standards Liaison (A. Allan Bates, Chief).

This office provided administrative liaison between the Bureau and engineering standards bodies, both domestic and international; evaluated Bureau engineering standards activities; and developed policy in this area. In keeping with his responsibilities, Bates published in 1967 a short note on engineering codes for the building industry.[83]

Office of Public Information (A. Victor Gentilini, Chief).

This office prepared press releases for the news media.

Office of Academic Liaison (Shirleigh Silverman, Chief).

The major responsibilities of this office were to keep the academic world and other government agencies aware of the types of work being done at NBS and to facilitate cooperative research with them. In pursuit of these goals, Silverman presented, at a symposium on biological science, a paper on the role of bioengineering in interdisciplinary research.[84]

Office of Program Development and Evaluation (Robert D. Huntoon, Chief).

This office was newly created in 1968 to provide the Director with guidance on programs, including in its recommendations relative priorities and information on the changing needs of U.S. science and industry.

Papers by Huntoon, for the journal *Science*[85] and for the journal *Physics Teacher*[86] provided insightful discussions of the principles of a *National Measurement System* for

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[83] A. A. Bates, "Building code viewpoints," *J. Bldg. Res. Inst.* **4**, No. 1, 48 (Jan. 1967).

[84] S. Silverman, *Reflections on bioengineering*, Bioengineering—An Engineering View, pp. 103-106 (San Francisco: San Francisco Press, Inc., June 1968).

[85] R. D. Huntoon, "Status of the National Standards for physical measurement," *Science* **150**, No. 3693, 169-178 (Oct. 8, 1965).

[86] R. D. Huntoon, "The basis of our measurement system," *Phys. Teacher* **4**, No. 3, 113-120 (March 1966).

physical quantities and helped define the intent of the new office. The concept of a national measurement system for each of the different measurement units was new at that time, part of an effort originating with Allen Astin to refine and publicize the mission of NBS.

Office of the Deputy Director (Irl C. Schoonover, Deputy Director, NBS)

Apart from providing daily assistance to Director Astin and acting on his behalf when necessary, the Deputy Director also supervised several administrative units. The Office of International Relations, the Office of Technical Information and Publications, the Library Division, the Instrument Shops Division, and the Measurement Engineering Division all reported directly to him.

Office of International Relations (Ladislaus L. Marton, Chief).

The OIR provided services to ease the path to NBS for visitors from other countries, as well as assisting NBS staff traveling abroad. Marton, famous for his scientific work in electron microscopy, not only served as Chief of the OIR in 1968, but he was still publishing technical papers at 67 years of age.[87] Before Astin left office, however, he relieved Marton of his OIR responsibility, replacing him with H. Steffen Peiser. Peiser, born in Europe and educated at Cambridge University in England, was—like Marton—a natural choice to represent NBS to its foreign peers. Besides his cosmopolitan upbringing and a flair for language, he was an expert crystallographer, he had lectured in physics at the university level, and he possessed the virtue of tact in abundance.

Office of Technical Information and Publication (W. Reeves Tilley, Chief).

Tilley supervised a section devoted to the staging of special events for NBS, publications-oriented sections that included editorial, redacting, photographic, and illustration capabilities, and a computer-assisted-printing section. His groups rendered assistance to all Bureau staff members in preparing their work for publication. In addition, they prepared motion pictures on Bureau projects, scheduled tours, interacted with the technical press, arranged conferences, and responded to queries from the public.

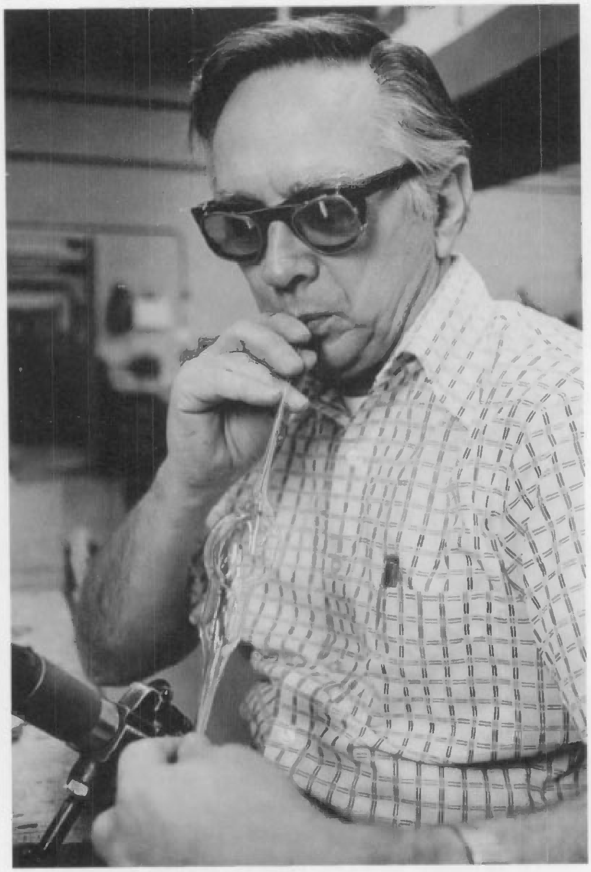
[87] L. Marton, "Progress in electron physics during the last 20 years," pp. 17-25 in Proc. Third Czechoslovak Conf. Electronics and Vacuum Physics, Prague, Czechoslovakia, Sept. 13, 1965 (Czechoslovak Academy of Sciences, Prague, 1967). A biography of Marton was written by Charles Süsskind, "L. L. Marton, 1901-1979," *Advances in Electronics and Electron Physics, Supplement 16*, p. 501 (Academic Press, Inc, 1985). Marton retired from NBS in July, 1970, after 24 years of service to the Bureau. Among his many awards was the Department of Commerce Gold Medal, presented in 1955. Marton was a member of the Royal Society of Belgium, the Graduate Faculty of Maryland, and (during 1962-63) the University of Paris. He was the author of several books on electron physics and microscopy.

Library Division (Elizabeth L. Tate, Chief).

Besides conventional library services, the Library Division provided bibliographic, reference, and translation services, and it served as a focal point for legislative materials and information issued by other Federal agencies.

Instrument Shops Division (Frank P. Brown, Chief).

Staffed by experienced machinists, draftsmen, and other shops experts, the Instrument Shops designed, constructed, and repaired high-precision instruments and auxiliary equipment for the use of Bureau scientists.



Allan M. Houck worked in the National Bureau of Standards instrument shops for over two decades. Most of those years were spent in the glassblowing shop where Houck was called on by Bureau scientists to manufacture custom glassware to very close tolerances.

Butch Robinson, mechanic in the National Bureau of Standards instrument shops, selected an arbor and a collet from the shops' instrument crib for use in fabricating one-of-a-kind scientific apparatus.

This group was mirrored by a shops division at the Boulder site.

Measurement Engineering Division (G. Franklin Montgomery, Chief).

The MED provided consultations in the area of measurement technology, including electronics, optics, thermometry, and mechanical systems.

Office of the Associate Director for Administration (Robert S. Walleigh, Associate Director for Administration).

In 1964 the Associate Director for Administration had been given new and manifold responsibilities, all dedicated to the objective of keeping the Bureau running smoothly. Walleigh managed the NBS buildings, plants, and other non-scientific facilities, in addition to supervising several administrative functions. The effectiveness of Walleigh as an administrator had led Astin to entrust him with the management of this large and complex domain.

Patent Advisor (David Robbins).

David Robbins provided assistance with patent searches, advice on patent-related record-keeping, and information on disclosure processes for the NBS staff. He also provided similar assistance to other Commerce employees. In addition to these activities, Robbins recently had prepared a note on a semi-automatic editing machine.[88]

Accounting Division (James P. Menzer, Chief).

This division housed the central NBS fiscal records. It also was the focus of the Bureau's accounting activities—billing, payments, test administration, and financial reports.

Administrative Services Division (George W. Knox, Chief).

George Knox supervised the distribution of Bureau mail, janitorial services, the guard force, safety, emergency planning, transportation, and special services such as the maintenance of the Bureau's lecture rooms and lecture equipment. It also maintained an NBS records holding area.

Budget Division (James E. Skillington, Jr., Chief).

Skillington advised NBS managers on the preparation, review, and presentation of the budget. He was responsible for maintaining fiscal balance between income and expenses for all NBS programs.

Personnel Division (George R. Porter, Chief).

The Personnel Division was the center for recruitment, placement, and classification of employees, as well as employee development. It also provided the focus for employment policies such as evaluation and promotion criteria.

Plant Division (Hylton Graham, Chief).

Personnel of this division repaired and improved the buildings and grounds at the Gaithersburg site and served as a focal point for similar work at other NBS locations.

Supply Division (George B. Kefover, Chief).

George Kefover had supervisory responsibility for property records and procurement and acted as the contracting officer for the Bureau.

Management & Organization Division (John T. Hall, Chief).

John Hall was responsible for maintaining management policies, for employee training and development, for preparing and circulating management announcements, and for creating management records and forms.

[88] D. Robbins, editor, *Disclosure on: Autoeditor—a semi-automatic copy-editing apparatus,* NBS Technical Note 440, April 1968.

Institute for Basic Standards (Ernest Ambler, an expert in cryogenic physics, was newly appointed in 1968 as Director, IBS).

The main responsibility of the IBS was to provide a central national basis for a complete system of physical measurements, internally consistent and in harmony with international standards. A second task was to develop, maintain, and disseminate standards to facilitate measurement of physical quantities in America's technical activities. The IBS also was called to provide measurements of critically needed physical properties.

The measurement of physical quantities was an important and continuing preoccupation Standards. The concerns of this Institute included development and maintenance of standard units of measurement[89] as well as the application of these standards to particular problems of technical importance. In this section we provide a few examples to characterize the efforts of the IBS.

Henry L. Mason, internationally renowned for his research on the application of computer technology to scientific problems, filled the post of *Coordinator for Measurement Services* until the fall of 1968. Mason reviewed the work of IBS calibration services, focusing especially on the quality of the data analysis that supported the various services. He acted as a point of contact between calibration personnel and NBS statisticians, often helping the services to improve the presentation of their results.

During 1968, an Office of Measurement Services was created within IBS to increase the visibility of the function that Henry Mason had performed. Joseph M. Cameron was appointed Acting Chief. Cameron had received the Department of Commerce Gold Medal Award for Exceptional Service in 1963 for "outstanding success in winning acceptance of statistical engineering as a research tool in physical science and engineering." His interest in that topic had not waned; in 1969 Cameron published a note for the journal *Technometrics* on the role of the statistical consultant in scientific work.[90]

Office of Standard Reference Data (Edward L. Brady, Chief).

The staff of this office coordinated the critical evaluation of the quality of sets of data that were basic to the success of a great variety of national scientific, technical, and engineering projects. In 1968, long-time efforts in this area were formalized by Congress in Public Law 90-396 (82 Stat 339), *The Standard Reference Data Act.* Among the long list of organizations cooperating with NBS on this project were the Chemical Abstracts Service of the American Chemical Society, the American Institute of Physics, the Engineers Joint Council, the Atomic Energy Commission, the Department of Defense, and the National Aeronautics and Space Administration.

[89] These standards were embodied in the International System of Units (SI), defined by the 11th and the 12th General Conferences on Weights and Measures in Paris.

[90] J. M. Cameron, "The statistical consultant in a scientific laboratory," *Technometrics* **11**, No. 2, 247 (1969).

The relatively small staff of the OSRD included: Stephen A. Rossmassler, whose responsibility lay in the area of atomic and molecular data; Lewis H. Gevantman, chemical kinetics and mechanical properties; Howard J. White, Jr., colloid and surface chemistry, thermodynamics, and transport data; Herman M. Weisman, information services; Joseph Hilsenrath, design of information systems; and David T. Goldman, nuclear data. Their efforts were multiplied many times over by assistance from NBS experts and from other technical organizations.

After completion of baccalaureate and masters degrees in chemistry at the University of California at Los Angeles, Brady joined one of the major laboratories of the atomic bomb project at the University of Chicago in 1942. His war-time work included a stint at the forerunner of the Oak Ridge National Laboratory, where he helped design and operate the first large-scale high-level-radioactivity facilities for the U.S. nuclear program. Following World War II, he completed doctoral studies in nuclear physics at the Massachusetts Institute of Technology, then in succession held positions in nuclear science at the *General Electric Knolls Atomic Power Laboratory*, with the *U.S. Atomic Energy Commission*, and with the *General Dynamics Corporation*. When NBS established the *National Standard Reference Data System* in 1963, Brady was recruited to head the program. He retained a personal interest in the NSRDS activity until his death in 1987, although he accepted an appointment as *Associate Director of NBS for International Affairs* in 1978, in which post he was successful in creating agreements with the USSR and China on the exchange of scientific information.

Brady described the work of the NSRDS in an *NBS Technical Note* and for the *Journal of Chemical Documentation.*[91] In the Technical Note, he identified numerous projects supported by the NSRDS, as well as the scientists involved in the research.

Data Needs and Compilations

One example of the types of work done under the NSRDS program was that of gathering information. Herman M. Weisman and his colleague Gerda B. Sherwood used the results of a questionnaire sent by the American Chemical Society to its members, asking about their needs and resources for critically evaluated property data on a variety of materials. Using this information, they prepared a list of data compilations. Some 16,000 replies, analyzed for the NSRDS, revealed a high level of need and, surprisingly, a number of compilation activities previously unknown to the system.[92]

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[91] Edward L. Brady, editor, *STATUS REPORT: National Standard Reference Data System*, NBS Technical Note 448, June 1968. See also E. L. Brady, "The National Standard Reference Data System," *J. Chem. Doc.* 7, No. 1, pp. 6-9 (1967).

[92] H. M. Weisman and G. B. Sherwood, "Annotated accession list of data compilations of the NBS Office of Standard Reference Data," *NBS Technical Note 554*, September, 1970, 196 pp.

An excellent example of the encouragement offered by NSRDS to outside groups to prepare much-needed technical information is provided by *NBS Technical Note 482,* compiled by Ben W. Roberts of the General Electric Research and Development Center in Schenectady, NY.[93] This compilation, based on an earlier effort published in the journal *Progress in Cryogenics,*[94] brought up to date the most important superconductive properties of hundreds of elements, compounds, and alloys. It also included more than 700 references to original data papers, review articles, and books, thus collecting in one handy publication a great deal of information of interest to experimentalists and theoreticians alike.

National Standard Reference Data Series

The initial publications of the NSRDS took the form of *National Standard Reference Data Series* publications, issued serially whenever contributions were ready. One publication in the NSRDS series, Section 2 of NSRDS-NBS 3, prepared by Charlotte E. Moore of the Atomic Physics Division, was devoted to the analysis of optical spectra of Si I.[95] Another contribution, a critical analysis of the literature on the heat capacity of the noble metals and an evaluation of their thermodynamic properties for temperatures between 0 K and 300 K, was prepared by George T. Furukawa, William G. Saba, and Martin L. Reilly of the Heat Division.[96]

A third contribution to the NSRDS series during this period was made by Lester Haar of the Heat Division, who evaluated the thermodynamic functions of ammonia as an ideal gas.[97]

Walter J. Hamer of the Electricity Division prepared NSRDS tables of theoretical activity coefficients for strong electrolytes in water solutions based upon seven different widely used expressions for these coefficients.[98]

Critical Reviews

An 80-page discussion of the excitation of atoms by electron impact was presented by Stephen J. Smith of JILA and his colleague Benjamin L. Moiseiwitsch of the Queen's University of Belfast, Northern Ireland.[99] This critical review was divided into

[93] B. W. Roberts, *Superconductive Materials and Some of Their Properties,* NBS Technical Note 482, May 1969.

[94] B. W. Roberts, "Superconductive Materials and Some of Their Properties," *Progress in Cryogenics 4,* pp. 160-231 (1964).

[95] Charlotte E. Moore, *Selected Tables of Atomic Spectra: A. Atomic Energy Levels—Second Edition. B. Multiplet Tables: Si I.,* National Standard Reference Data Series-U.S. National Bureau of Standards, NSRDS-NBS 3, Section 2, November 30, 1967.

[96] George T. Furukawa, William G. Saba, and Martin L Reilly, *Critical Analysis of the Heat-Capacity Data of the Lierature and Evaluation of Thermodynamic Properties of Copper, Silver, and Gold from 0 to 300 °K,* NSRDS-NBS 18, April 1968.

[97] Lester Haar, *Thermodynamic Properties of Ammonia as an Ideal Gas,* NSRDS-NBS 10, August 1968.

[98] Walter J. Hamer, *Theoretical Mean Activity Coefficients of Strong Electrolytes in Aqueous Solutios from 0 to 100 °C,* NSRDS-NBS 24 December 1968.

[99] B. L. Moiseiwitsch and S. J. Smith, *Electron Impact Excitation of Atoms,* NSRDS-NBS 25, August 1968.

theoretical discussions of excitations in hydrogen, helium, neon, argon, mercury, the alkali metals, oxygen and nitrogen, followed by an analysis of experimental work on most of the same elements. It contained more than 200 references to original papers and more than 60 tables of data.

Data Centers

David Garvin and Henry M. Rosenstock provided information on data centers for chemical kinetics and mass spectrometry for the *Journal of Chemical Documentation.* In their discussion, they compared the methods of operation of the centers, including the methods of evaluation and retrieval.[100]

Stephen A. Rossmassler described the NSRDS center for atomic and molecular properties for a symposium on the compilation of data on chemical and physical properties.[101]

The NBS Alloy Data Center, formed to stimulate cooperation among groups generating physical-property information on well-characterized alloys and to aggregate the data in one location, was described in some detail by Gesina Carter with the assistance of Lawrence H. Bennett, John R. Cuthill, and Daniel J. Kahan.[102] Not only did the Center utilize an automated retrieval system, but its staff also maintained an up-to-date bibliography.

Handbooks

During 1968 NBS Handbook 101 *OMNITAB, A Computer Program For Statistical and Numerical Analysis* went into its second printing. Originally prepared for the Heat Division by Joseph Hilsenrath, Guy G. Ziegler, Carla G. Messina, Philip J. Walsh, and Robert J. Herbold the handbook described *OMNITAB,* a general-purpose digital computer program that enabled the average scientist to use computers in analyzing data and performing other calculations even though he or she was not familiar with the usual programming languages. The occasion of the second printing was used to make corrections and clarifications in the original text and to add an illustrative appendix by David Hogben. Hilsenrath and Alfred E. Beam, a colleague from the University of Maryland (and a former NBS staff member), published a full description of a multiple-precision version of OMNITAB.[103] The new program, labeled *PRECISE,* mitigated the loss of precision that ordinarily resulted from round-off operations in numerical computing.

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[100] D. Garvin and H. M. Rosenstock, "Two National Bureau of Standards data centers—chemical kinetics and mass spectrometry," *J. Chem. Doc.* **7**, No. 1, 31-34 (Feb. 1967).

[101] S. A. Rossmassler, "The National Standard Reference Data System program in atomic and molecular properties" (Proceedings of a Symposium on Compilations of Data on Chemical and Physical Properties of Substances, 152nd National Meeting, Am. Chem. Soc., New York, NY, Sept. 12, 1966), *J. Chem. Doc.* **7**, No. 1, 15-18, February 1967.

[102] Gesina C. Carter with L. H. Bennett, J. R. Cuthill, and D. J. Kahan, *The NBS Alloy Data Center: Function, Bibliographic System, Related Data Centers, and Reference Books,* NBS Technical Note 464, August 1968.

[103] Alfred E. Beam and Joseph Hilsenrath, *PRECISE: A Multiple Precision Version of Omnitab,* NBS Technical Note 446, June 1968.

Computerized Data Programs

With colleague Robert C. McClenon, Hilsenrath also described a new general-purpose program for manipulating formatted data.[104]

Also described during this period was a group of five utility computer programs written in the Fortran language to make overall changes in existing data sets.[105]

Applied Mathematics Division (Edward W. Cannon, Chief).

The origin of an applied mathematics unit at NBS dated to 1946, when Director Edward Condon hired Churchill Eisenhart, one of the first mathematicians to graduate from Princeton University in the specialty of statistics.[106] Condon realized the value of creating at the Bureau the capability to apply the rigor of statistics to scientific measurements, which generally feature data sets much smaller than were suited to the generation of ordinary statistical manipulations, and he knew from personal experience that Eisenhart shared his view. To create such an applied mathematics group, Eisenhart hired Lola Deming, Helen Herbert, Joseph M. Cameron, and William J. Youden.[107] This group became the nucleus of a Statistical Engineering Laboratory.

In 1963 Eisenhart was appointed Senior Research Fellow and was assigned to the Office of the Director. He retired from NBS in 1983 with many honors for the high quality of his work.

The Applied Mathematics Division staff utilized the methods of mathematics and statistics to assist in the development of new measurement techniques and to evaluate the results of measurement. The staff also performed a variety of other research and service functions.

The work of the division was separated into sections on operations research, led by Alan J. Goldman; statistical engineering, headed by Joseph M. Cameron until he was reassigned to head the Office of Measurement Services, then placed under the leadership of Joan Rosenblatt; numerical analysis, under Morris Newman; and systems dynamics, under the guidance of Hans J. Oser.

[104] Robert C. McClenon and Joseph Hilsenrath, "A General-Purpose Program for Manipulating Formatted Data Files," *NBS Technical Note 444,* August 1968.

[105] Carla G. Messina and Joseph Hilsenrath, "EDPAC: utility programs for computer-assisted editing, copy-production, and data retrieval," *NBS Technical Note 470,* January 1969.

[106] Ingram Olkin, "A Conversation With Churchill Eisenhart," *Statistical Science,* Vol. 7, No. 4, pp. 512-530 (1992).

[107] The hiring of Youden illustrates a strength of NBS—its attraction as a fine place to work. Eisenhart state in his oral history that he was reluctant to approach Youden, a well-known statistician then employed by Rand Corporation at a salary of perhaps $15,000 per year, about coming to work at the Bureau, where the *Director's* salary was only $9,000. When approached, however, Youden confessed to a long-term desire to be associated with NBS and paid little mind to the pay cut. Youden was a productive applied mathematician at NBS until his death in 1971.

The Statistical Engineering section served an unusual purpose for all the Bureau staff: it offered direct assistance in statistical analysis. Those scientists who needed to evaluate uncertainties of measurement in the preparation of SRMs, those who were assessing the results of fundamental measurements, and other Bureau staff involved in the analysis of data could receive assistance from section personnel in the often-arcane generation of accurate statistical values. Volume 1 of *NBS Special Publication 300,* edited by Harry H. Ku, provided much-valued guidance with sections entitled The Measurement Process, Design of Experiments in Calibration, Interlaboratory Tests, Functional Relationships, and Statistical Treatment of Measurement Data.[108] Certain examples for this text came from actual NBS calibration work.

Information Theory

With the collaboration of S. Kullback of the George Washington University, Ku utilized an information-theory approach to the problem of interaction in multi-dimensional contingency tables, including illustrative examples.[109]

The division staff applied their efforts to problems arising in other government agencies as well as NBS. Division personnel conducted fundamental mathematical research in several areas.

Consumer Trends

In an investigation supported by the Department of Commerce Office of High-Speed Ground Transportation, J. M. McLynn, Alan J. Goldman, Philip R. Meyers, and R. H. Watkins analyzed mathematically how the "market"—a group of consumers—might divide its buying among competing products.[110]

Data Retrieval

An intensive study of the usefulness of multiple-access computer-retrieval methods for searching the scientific citation literature was performed by Franz L. Alt and Russell A. Kirsch.[111] It was hoped that the study, which involved a group of NBS physicists and citations in some 25,000 physics publications, would help to refine such methods in the future.

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[108] "Precision measurement and calibration. Selected papers on statistical concepts and procedures," *NBS Special Publication 300; 1*, H. H. Ku, editor, February 1969, 436 pp.

[109] H. H. Ku and S. Kullback, "Interaction in multidimensional contingency tables; an information theoretic approach," *J. Res. NBS, 72B,* No. 3, 159-199 (1968).

[110] J. M. McLynn, A. J. Goldman, P.R. Meyers, and R. H. Watkins, "Analysis of a market split model," *J. Res. NBS, 72B,* No. 1, pp. 43-60 (1968).

[111] F. L. Alt and R. A. Kirsch, "Citation searching and bibliographic coupling with remote on-line computer access," *J. Res. NBS 72B,* No. 1, pp. 61-78 (1968).

Responsibilities of Other IBS Divisions

Each division of IBS except the Applied Mathematics Division shared a variety of specialized functions. Among these were the following:

- Develop and maintain U.S. standards of physical measurement, including multiples and sub-multiples as appropriate, and develop transfer standards and standard instruments.
- Calibrate instruments in terms of the national standards and provide other needed services to promote the accuracy and uniformity of physical measurements.
- Provide advisory services to other government agencies and to U.S. science and industry on basic measurement problems.
- Correlate with other nations the standards and definitions in measurement science.
- Determine values for relevant fundamental physical constants.
- Conduct experimental and theoretical studies of physical phenomena that might be relevant to the creation of new measurement methods or standards.

Meeting these requirements required each division to maintain a staff of highly capable scientists, as well as world-class calibration personnel and facilities. It is a testament to the competence of Bureau management that, for the most part, these goals were reached.

Electricity Division (Chester H. Page, Chief).

The Electricity Division grouped its activities into sections on resistance and reactance, headed by Chester Peterson; electrochemistry, under Walter J. Hamer; electrical instruments, led by Francis L. Hermach; high voltage, under F. Ralph Kotter; and absolute electrical measurements, headed by Forest K. Harris.

As listed in the *NBS Special Publication 250,* Electricity Division personnel provided a number of calibration services to the public and to other governmental organizations, including the following types:[112]

- Electrical resistance, inductance, capacitance, and emf.
- Electrical instruments.
- Voltage ratios and high-voltage measurements.
- Dielectric constants and dissipation factors.
- Magnetic induction, hysteresis, permeability, core loss, and fluxmeters.

[112] *Calibration and Test Services of the National Bureau of Standards*, NBS Special Publication 250, May 1968. NBS Special Publication 250 constitutes a series of documents announcing and describing the many Bureau calibration services. The series was begun in November 1963.

Special Publication 300

In 1968 there were published two volumes of NBS Special Publication 300, a multi-volume compendium on specialized topics in the area of high-precision measurement and calibration. These volumes were used as reference sources by metrologists throughout the world. Replacing a similar series published in the 1950s as *NBS Handbook 77,* SP 300 was intended to present up-to-date reprints of papers in a dozen standards areas.

One of the SP 300 volumes, No. 3, covered the field of electricity; it was edited by Francis L. Hermach and Ronald F. Dziuba.[113] Nearly 500 pages long, it contained reprints of 45 papers and nearly as many abstracts of papers dealing with standard cells and Zener diodes, resistors and resistance-measurement equipment, capacitors, inductors, ac-dc transfer standards, transformers and inductive voltage dividers, high voltages, dielectrics, magnetic measurements, and general papers on electrical standards. The interested reader could find in its pages information on, or at least references to, most contemporary electrical standards work.

Electric Charge

One of the electrical measurement quantities to which NBS contributed significantly was electric charge. The classical method used in determining values of the unit of electric charge, at that time known as the Faraday, involved the electrolytic deposition of silver from an aqueous solution of silver nitrate. However, many other methods were used as well. A summary of values obtained by five different methods, converted to the contemporary unified ^{12}C international scale of atomic weights, was given by Walter J. Hamer. He compared the values of the Faraday as determined by Norman Craig and James I. Hoffman using silver deposition, iodide oxidation, oxalate oxidation, silver dissolution, and the omegatron instrument. A recommended value of $(96{,}487.0 \pm 1.6)$ coulombs/gram-equivalent, using the dissolution of silver in aqueous solutions, proved most reliable. The results varied by as much as one part in 10,000.[114]

Later (see Sect. 4.5.1), Richard S. Davis and Vincent E. Bower, using improved methods, would bring measurements of the Faraday to a new level of accuracy—better than 1 ppm.

At present, the SI unit of electric charge is the coulomb.[115]

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[113] *Precision measurement and calibration. Selected NBS papers on electricity—low frequency,* F. L. Hermach and R. F. Dziuba, editors, NBS Special Publication 300, Volume 3, December 1968, 498 pp.

[114] W. J. Hamer, "Résumé of values of the Faraday," *J. Res. Nat. Bur. Stand. (U.S.),* **72A**, No. 4, 435-439 (1968).

[115] See, for example, Barry N. Taylor, "Guide for the use of the International System of Units (SI)," *NIST Special Publication 811, 1995 Edition,* April 1995, p. 50.

Capacitance Standards

The quality of the standard for capacitance improved noticeably at that time as a result of a collaboration between the National Measurement Laboratory (NML) of Australia and NBS. A.M. Thompson and D.G. Lampard of NML initiated the work with a new theoretical discussion of capacitance. They followed their advance by developing new practical standards and measurement techniques in a long-term collaboration with Robert D. Cutkosky, John Q. Shields, and Lai H. Lee of the NBS Electricity Division.

Cutkosky and Lee reported development of an improved, transportable 10 pF capacitor during a 1965 meeting of the Consultative Committee for Electricity at the International Bureau of Weights and Measures in Paris.[116] Later, Cutkosky reported a new value for the absolute farad obtained with the new tools;[117] it stood as the world's best for a decade.

Voltage Standards

The Bureau's voltage standard in 1968 resided in a bank of saturated standard cells. The NBS realization of the volt was derived from intercomparisons of these cells, so that the methods used in performing the intercomparison were significant. In an example of the usefulness of the statistical capabilities of the staff of the NBS Office of Measurement Services, Joseph Cameron of that office collaborated with Woodward G. Eicke in designing procedures for monitoring the NBS collection of standard cells.[118]

Zener diodes, much easier to maintain than electrochemical cells, were calibrated at the Bureau as secondary-level voltage standards. Eicke and Henry H. Ellis prepared for long-term study a group of these diodes of normal voltage 8.1 V to 9.2 V. During the study, the devices were maintained within 0.02 °C of 25 °C. The authors tracked the stability of the group of devices over a 3 year period. The level of voltage stability of the diodes over the period ranged from 3 ppm to 10 ppm, as reported during a meeting of the Consultative Committee for Electricity at the International Bureau of Weights and Measures in Paris.[119]

The problem of comparing ac voltages to dc standard voltages at high accuracy became more significant as advances in operational amplifiers and inductive voltage

[116] R. D. Cutkosky and L. H. Lee, *An improved transportable ten picofarad capacitor*, Proceedings of the 11th Session of the Consultative Committee for Electricity, May 10-12, 1965 (BIPM, Paris, France).

[117] R. D. Cutkosky, "New NBS measurements of the absolute farad and ohm" *IEEE Trans. Instrum. Meas. IM-23*, No. 4, 305-309 (1974).

[118] W. G. Eicke and J. M. Cameron, *Design for the surveillance of the volt maintained by a small group of saturated standard cells*, NBS Technical Note 430, October 1967.

[119] W. G. Eicke and H. H. Ellis, *On long-term stability of Zener reference diodes*, Proceedings of the 11th session of the Consultative Committee for Electricity, May 10-12, 1965 (BIPM, Paris, France).

dividers achieved linearity and day-to-day stability levels better than 100 ppm. Francis L. Hermach conceived the idea of using thermal converters for ac/dc comparisons; he performed careful studies to elucidate the frequency dependence of the devices.
Earl S. Williams and Hermach assembled a group of thermoelements which they examined at audio frequencies at currents from 5 mA to 20 mA. They found that they could evaluate the ac-dc differences with uncertainties of about 2 ppm. Inserting these thermoelements into circuits with a range of series resistors to create thermal voltage converters, they were able to measure voltages in the range 0.5 V to 500 V with uncertainties less than 10 ppm.[120]

A new method for self-calibration of inductive voltage dividers was described by Wilbur C. Sze. Characterized as a "boot-strapping" injection method, the new technique was suggested for determining both in-phase and quadrature deviations. Advantages of the new technique over earlier methods were discussed as well.[121]

Metrology Division (Theodore R. Young, Acting Chief).

The Metrology Division consisted of three branches. One of these specialized in optical techniques under the leadership of Louis E. Barbrow. It was composed of sections in photometry led by Charles A. Douglas, another in image optics and photography under Calvin S. McCamy, and a third in colorimetry and spectrophotometry headed by Isadore Nimeroff. A second branch, in length metrology, was headed by Young himself. It consisted of a section on length led by John S. Beers, and another on engineering metrology headed by Arthur G. Strang. A third branch, in mass and volume metrology, was headed by Paul E. Pontius.

Calibration and testing services provided by the staff of the Division included the following services listed in *NBS Special Publication 250*:

- Photometry.
- Image Optics and Photography.
- Spectrophotometry.
- Length.
- Engineering Metrology (length and diameter, end standards, step gages, threads and gears, spherical diameters, internal diameters and ring gages, master gears, calipers, flatness, straightness, optical reflecting planes, roundness, surface texture, angles, mass, volume, and density).

[120] F. L. Hermach and E. S. Williams, "Thermal converters for audio-frequency voltage measurements of high accuracy," *IEEE Trans. on Instr. and Meas.* **IM-15**, No. 4, pp. 260-268 (1966).

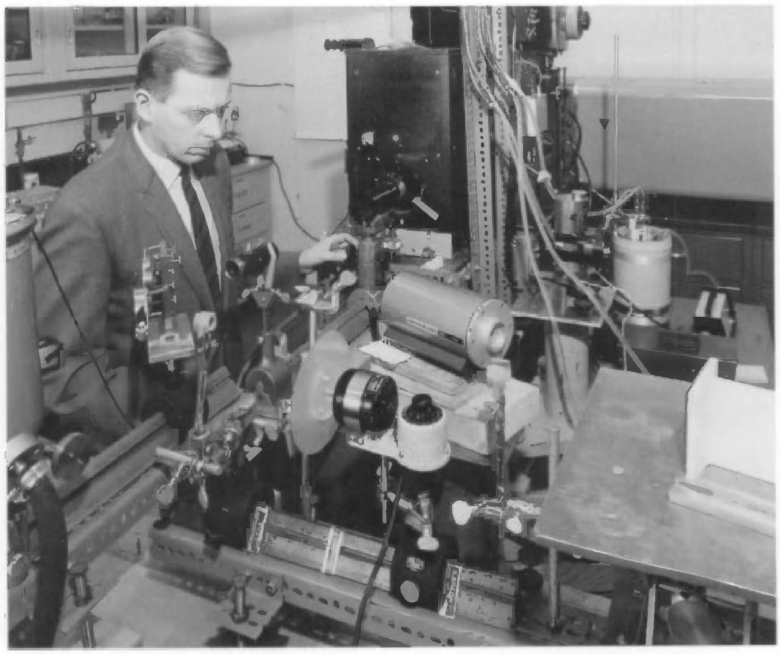
[121] W. C. Sze, "Comparator for calibration of inductive voltage dividers from 1 to 10 kHz," *ISA Trans.* **6**, No. 4, 263-267 (Oct. 1967).

International Comparison of Laser Wavelengths

Laser wavelength calibrations, undertaken jointly by scientists at NBS, at the National Physical Laboratory in England, and at the Physikalisch-Technische Bundesanstalt in Germany, showed agreement among stabilized helium-neon lasers at the level of 5 parts in 10^8 in wavelength. Bureau scientists involved in this type of measurement included Klaus D. Mielenz and Karl F. Nefflen of the Metrology Division.[122]

Mass Measurement

With the assistance of Joseph Cameron of the Office of Measurement Services, Paul E. Pontius reviewed the procedures for accurate mass measurement.[123] Included in



Klaus D. Mielenz aligned the apparatus used at NBS to measure laser wavelengths as part of an international study. Light from a standard ^{86}Kr lamp (extreme left) was brought to a common focus along with a helium-neon laser beam. The beams were then recollimated to illuminate an interferometer (upper center). The ring pattern produced by the interferometer was photographically recorded by a spectrograph. Finally a computer was used to calculate the laser wavelength relative to the ^{86}Kr standard.

[122] K. D. Mielenz, R. B. Stephens, K. E. Gillilland, and K. E. Nefflen, "Measurement of absolute wavelength stability of lasers," *J. Opt. Soc. Am.* **56,** No. 2, 156-162 (1966).

[123] P. E. Pontius and J. M. Cameron, "Realistic uncertainties and the mass measurement process. An illustrated review," *NBS Monograph 103,* August 1967.

this discussion was the idea of incorporating a laboratory standard in the calibration routine as an unknown, to provide a check on the quality of the calibration process; this technique became the basis for *Measurement Assurance Programs.*

Line Standards

The use of a 633 nm helium-neon laser as a light source for an automatic fringe-counting interferometer made possible an improved calibration technique for line standards, leading to uncertainties less than 0.1 ppm. The advance was made through a collaborative effort involving Kitt E. Gillilland, Herbert D. Cook, Klaus D. Mielenz, and Robert B. Stephens.[124]

Microfilm Storage

In a continuing study of problems related to the storage of microfilm, performed in part at the request of the U.S. Library of Congress, Chester I. Pope reported on the effects that the details of the film processing procedures could cause later in storage. [125] Pope and his colleague Calvin S. McCamy had recently published several discussions on this topic.[126] During this period McCamy also reviewed photographic standardization and research at NBS for the journal *Applied Optics.* [127]

Color

Deane B. Judd, soon to retire after an illustrious scientific career at NBS, wrote an extensive summary work on color vision and colorimetry for the second edition of the *Handbook of Physics,* a comprehensive tome originally prepared during the years 1948-1958 under the editorship of Edward Condon, then Director of NBS, and Hugh Odishaw.[128]

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[124] K. E. Gillilland, H. D. Cook, K. D. Mielenz, and R. B. Stephens, "Use of a laser for length measurements by fringe counting," *Metrologia* **2**, No. 3, 95-98 (1966).

[125] C. I. Pope, "Blemish formation in processed microfilm," *J. Res. NBS* **72A**, No. 3, 251-259 (1968).

[126] C. S. McCamy, "Inspection of processed photographic record films for aging blemishes," *NBS Handbook 96* (Washington, DC: USGPO, 1964). See also,

C. S. McCamy and C. I. Pope, "Summary of current research on archival microfilm," *NBS Technical Note 261* (Washington, DC: USGPO, 1965).

[127] C. S. McCamy, "Photographic standardization and research at the National Bureau of Standards," *Appl. Opt.* **6**, No. 1, 27-30 (1967).

[128] D. B. Judd, "Color vision and colorimetry," Chapter 4 in *Handbook of Physics,* Second Edition, Part 6, Optics, E. U. Condon and H. Odishaw, editors, McGraw-Hill, NY, 1967, pp. 6-65 to 6-77. Judd retired after 42 years at NBS in October 1969. At that time, he held the honorific position of Senior Research Scientist. Among many awards for his scientific achievements were the Department of Commerce Gold Medal (1950), the Frederic Ives Medal of the Optical Society of America (1958), the Gold Medal of the Illuminating Engineering Society (1961), and the NBS Stratton Award (1965).

Another substantial work on colorimetry, *NBS Monograph 104,* written by Isadore Nimeroff, was published in January 1968.[129] The monograph superseded *NBS Circular 478,* dating from 1950, which had been reprinted several times but had become obsolete in many respects. Parts of the original text were retained where they were correct and useful. Aspects of the topic included the involvement of the eye in defining color, early color standards, colorimetry by comparison, colorimetry by material standards, and color scales.

As part of a continuing investigation into color vision, Gerald L. Howett reported the results of a study of the variation in the shape of spectral absorptance curves obtained using pigment solutions of varying concentration. He discussed his results in terms of the current theory of color vision.[130]

An NBS research associate from IBM Corp., Carl F. Shelton, determined the photo-excitation, spectral-emission properties of 10 phosphor samples issued as standards by NBS.[131] Radiation was observed at 253.7 nm and 365 nm.

Thermal Properties

Temperature-dependent properties of materials received attention from several NBS divisions. Bruce D. Rothrock and R. Keith Kirby completed the development of an apparatus for the measurement of thermal expansion of refractory materials at temperatures to 1600 °C.[132] The apparatus consisted of an optical comparator and a controlled-gradient vacuum furnace; it provided results estimated to be accurate within 50 ppm.

Kirby also completed measurements of the thermal expansion of a single crystal of TiO_2 (rutile) over the range 100 K to 700 K, using an Abb-Pulfrich interferometer to obtain the results in terms of the tetragonal symmetry of the crystal.[133]

Mechanics Division (Edward C. Lloyd, Acting Chief).

The Mechanics Division consisted of sections involved in measurements of sound, headed by Martin Greenspan; engineering mechanics, under Lafayette K. Irwin; and rheology, led by Robert S. Marvin. Lloyd himself supervised a branch for mechanical measurements: its sections included pressure measurements, also headed by Lloyd; vacuum measurements, under Stanley Ruthberg; vibration studies, led by Roscoe L. Bloss; and humidity measurements, headed by Arnold Wexler. A branch on fluid mechanics consisted of sections on fluid meters, led by Fillmer W. Ruegg; hydraulics, under Gershon Kulin; and aerodynamics.

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[129] I. Nimeroff, "Colorimetry," *NBS Monograph 104,* January 1968, 50 pp.

[130] G. L. Howett, "Variation of absorptance-curve shape with changes in pigment concentration," *J. Res. NBS* **72A**, No. 4, 309-340, 1968.

[131] Carl F. Shelton, "Spectral Emission Properties of NBS Standard Phosphor Samples Under Photo-Excitation," *NBS Technical Note 417,* March 1968.

[132] B. D. Rothrock and R. K. Kirby, "An apparatus for measuring thermal expansion at elevated temperatures," *J. Res. NBS* **71C**, 85-91 (1967).

[133] R. K. Kirby, "Thermal expansion of rutile from 100 to 700 °K," *J. Res. NBS* **71A**, 363-369 (1967).

The division offered several calibration and test services, which were listed in *NBS Special Publication 250*:

- Acoustics.
- Vibration.
- Humidity.
- Engineering Mechanics (hardness, load cells, proving rings, and elastic force).

Arnold J. Mallinger inspected a proving ring before its calibration as a force standard in a deadweight machine at the National Bureau of Standards.

- Fluid Meters.
- Hydraulics.
- Aerodynamics.
- Pressure and Vacuum.
- Railroad Track Scales.

Humidity

The construction and use of a new adiabatic saturation psychrometer were described by Lewis Greenspan and Arnold Wexler.[134] The instrument was intended for use in atmospheric humidity measurements, but was tested for use in other vapor-gas combinations. Its uncertainty in humidity measurements was evaluated as +0.2 % of the reading. The new device was expected to be especially valuable in the fields of air conditioning and the chemical process industries.

Pressure

In an investigation of potential pressure-scale reference points, Peter L. M. Heydemann reported the use of a dead-weight piston gage to determine the pressure of the bismuth I−bismuth II transition at about 25.3 kbar (approximately 2.6 GPa).[135] He used two samples of different purity; the less-pure sample yielded a transition pressure about 1 % higher, well outside the estimated measurement uncertainty of 0.2 %.

In support of the use of the vapor pressure of carbon dioxide at 0 °C as a pressure-scale reference point, Daniel P. Johnson and his student, J. L. Edwards of The George Washington University in Washington DC, developed a dynamic method to determine that value.[136] The method involved the use of a controlled-clearance piston gage. The value obtained, 34.8516 bar, differed by as much as three parts in 10,000 from earlier measurements. The authors cautioned that the quality of the pressure measurements, the temperature environment, and the sample preparation were all of comparable importance to the success of the measurement.

Fluid Flow

A study of high-order correlations in turbulent fluid fields was reported by Philip S. Klebanoff and his associate François N. Frenkiel, a physicist at the David Taylor Model Basin in Carderock, Maryland.[137] Wishing to extend the analysis of turbulence that was found, for example, in air or water flow, in sea waves, or in acoustic noise, the authors constructed a grid of 0.5 cm diameter bars with a mesh size of 2.5 cm. They placed the grid in the NBS wind tunnel and recorded the turbulence thereby created in a 15 cm/s air flow some 50 diameters downstream from the grid. They pointed out the indications of non-Gaussian probability distributions in the experimental results, and they obtained several relations between correlation coefficients for these distributions.

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[134] L. Greenspan and A. Wexler, "An adiabatic saturation psychrometer," *J. Res. NBS* **72C** (Engineering and Instrumentation), No. 1, 33-47 (1968).

[135] P. L. M. Heydemann, "The Bi I-II transition pressure measured with a dead weight piston gage," *J. Appl. Phys.* **38**, No. 6, 2640-2644 (1967).

[136] J. L. Edwards and D. P. Johnson, "A dynamic method for determining the vapor pressure of carbon dioxide at 0 °C," *J. Res. NBS* **72C** (Engineering and Instrumentation), No. 1, 27-32 (1968).

[137] F. N. Frenkiel and P. S. Klebanoff, "Higher-order correlations in a turbulent field," *Phys. Fluids* **10**, No. 3, 507-520 (1967).

Gravity

Douglas R. Tate used the "free fall" method to measure the acceleration of gravity at a reference point in the Engineering Mechanics building in 1965; the value obtained was 980.1018 cm/s^2. In a 1968 *NBS Monograph,* No. 107, he described the experimental apparatus used, the techniques employed, and the data analysis on which the value was based.[138] Gradient techniques were utilized to transfer the measurement to another reference point in the gravity room of the Department of Commerce building in Washington, DC. That value was determined to be (980.1048 $\pm$ 0.0005) cm/s^2.

Force Measurement

Richard A. Mitchell provided an analysis of the various methods used to optimize the shape of proving rings and other elastic ring-type force transducers.[139] The intent of the project was to minimize the weight of the rings without losing the flexibility needed for the device.

Heat Division (Ralph P. Hudson, Chief).

The Heat Division consisted of sections on heat measurements, led by Defoe C. Ginnings; cryogenic physics, headed temporarily by James F. Schooley; equation of state, under Max Klein; statistical physics, led by Melville S. Green; temperature, under Harmon H. Plumb; and radiation thermometry, headed by Henry J. Kostkowski.

The division listed several calibration services in *NBS Special Publication 250*:

- Temperature (Liquid-in-glass, Thermocouple, and Resistance Thermometers).
- Cryogenic Resistance Thermometers.
- Radiation Thermometers and Standard Lamps.
- Radiometers.

Special Publication 300

In the notes on the Applied Mathematics and Electricity Divisions we called attention to *NBS Special Publication 300,* a multi-volume compendium on precision measurement and calibration. In 1968 Volume 2, *Temperature,* was published.[140] This 500-page volume was edited by James F. Swindells, former chief of the Temperature Section. Topics presented in the 30-some papers reprinted in the volume included the

[138] D. R. Tate, "Acceleration due to gravity at the National Bureau of Standards," *NBS Monograph 107,* June 1968, 24 pp.

[139] R. A. Mitchell, "Analysis of n-degree elliptical elastic rings of nonuniform cross section," *J. Res. NBS* **72C** (Engineering and Instrumentation), No. 2, 139-160 (1968).

[140] J. F. Swindells, editor, "Selected NBS papers on temperature," Volume 2 in *NBS Special Publication 300, Precision Measurement and Calibration,* August 1968, 520 pp.

expression of uncertainties, temperature scales, resistance thermometry, thermoelectric thermometry, liquid-in-glass thermometry, optical pyrometry, and spectroscopic thermometry. Most of the thermometry research that undergirded the International Practical Temperature Scale of 1968 was represented in this volume. A bibliography covering the period 1953-65 was appended to it.

Cryogenic Temperature Scales and Cryogenic Physics

A provisional temperature scale for the range 14 K to 20 K was put forth by Harmon H. Plumb and George Cataland in 1966. The scale relied upon the relationship between the saturated vapor pressure of liquid hydrogen and the temperature as determined by acoustic isotherms in helium gas.[141] This work also provided information on the second virial coefficient of ^{4}He in the same temperature range; the values were derived and published in a collaborative effort with Marjorie E. Boyd and Sigurd Y. Larsen of the Statistical Physics Section.[142]

A temperature scale for even lower-temperature use was described by Ralph P. Hudson, the division chief, and Robert S. Kaeser. By measuring the internal energy of cerous magnesium nitrate (CMN) as a function of its entropy, using magnetic cooling and gamma-ray heating, they were able to deduce the thermodynamic temperature, correlate it with the paramagnetic susceptibility of CMN, and thus to develop a scale that extended from 0.002 K to 2 K.[143]

As part of a study of the behavior of paramagnetic materials at low temperatures, Billy W. Mangum and Jack H. Colwell reported measurements of the heat capacity of neodymium and praseodymium chlorides in the range 0.3 K to 4 K. They interpreted the results in terms of the linear Ising model of paramagnetism.[144]

The thermodynamic properties of ammonia were studied intensively at NBS over a period of many years. The substance was used in refrigeration throughout the United States prior to the introduction of freons. During this period, Lester Haar evaluated and published values for several thermodynamic functions of ammonia as an example of a nearly ideal gas.[145]

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[141] H. Plumb and G. Cataland, "Acoustical thermometer and the National Bureau of Standards provisional temperature scale 2-20 (1965)," *Metrologia* **2**, No. 4, 127-139 (1966).

[142] Marjorie E. Boyd, Sigurd Y. Larsen, and Harmon Plumb, "Second virial coefficient of He^4 in the temperature range from 2 to 20 °K," *J. Res. NBS* **72A**, No. 2, 155-156 (1968).

[143] R. P. Hudson and R. S. Kaeser, "Cerous magnesium nitrate: a magnetic temperature scale 0.002-2 °K," *Physics* **3**, No. 2, 95-113 (1967).

[144] B. W. Mangum and J. H. Colwell, "Low-temperature heat capacity of $NdCl_3$ and $PrCl_3$," *J. Appl. Phys.* **38**, No. 3, 1468-1469 (1967).

[145] L. Haar, "Thermodynamic properties of ammonia as an ideal gas," *J. Res. NBS* **72A**, No. 2, 207-216 (1968).

Using the methods pioneered during the Bureau's "free radicals" program, Stanley Abramowitz, collaborating with Nicolo Acquista of the Atomic Physics Division, studied the infrared spectra of LiF embedded in matrices of argon cooled to low temperatures by liquid hydrogen.[146] The results were interpreted in terms of the formation of dimers or possibly trimers of LiF.

Progress to date on understanding the existence of superconductivity in semiconducting $SrTiO_3$ and mixed titanates was summarized in papers written by Ernest Ambler, Jack Colwell, Earl R. Pfeiffer, and James Schooley of the Heat Division and their colleagues Hans P.R. Frederikse, William R. Hosler, and W. Robert Thurber of the Inorganic Materials Division.[147, 148] The variability in the concentration of the electrical charge carriers in $SrTiO_3$, readily controlled in sample preparation, made it a particularly interesting superconductor since the temperature of transition to the superconductive state depended upon the carrier concentration. A theoretical correlation between charge-carrier concentration and superconducting transition temperature was developed by Calvin S. Koonce and his mentor from the University of California, Marvin L. Cohen.[149] This work won for Koonce the Distinguished Young Scientist Award of 1969 from the Maryland Academy of Sciences.

The first observation of the superconducting energy gap by electron tunneling in a semiconductor, GeTe, was reported by Schooley and his colleagues Philip J. Stiles and Leo Esaki of the IBM Watson Research Center in Yorktown Heights, NY.[150] Measurements were made by cooling an Al-Al_2O_3-GeTe tunnel junction to temperatures ranging from 0.085 K to 2.5 K in an adiabatic demagnetization cryostat, then measuring the conductance dI/dV *vs* V. At temperatures above 0.5 K the structure in the conductance due to the GeTe superconductivity disappeared.

[146] S. Abramowitz and N. Acquista, "Infrared matrix spectra of lithium fluoride," *J. Res. NBS* **72A**, No.5, 487-493 (1968).

[147] J. F. Schooley and W. R. Thurber, "Superconductivity in semiconducting $SrTiO_3$," *Proceedings of the International Conference on the Physics of Semiconductors,* Kyoto, Japan, September 8-11, 1966, *J. Phys. Soc. Japan* **21**, 639-642 (1966).

[148] E. Ambler, J. F. Schooley, J. H. Colwell, E. R. Pfeiffer, H. P. R. Frederiske, W. R. Hosler, and W. R. Thurber, "Transition temperatures and critical fields of $SrTiO_3$ and mixed titanates," *Proc. Xth Intern Conf. Low Temperature Physics, Moscow, USSR, Aug 31-Sept 6, 1966,* Vol. 2B, *Superconductivity,* Paper S123, 142-148 (1968).

[149] C. S. Koonce, M. L. Cohen, J. F. Schooley, W. R. Hosler, and E. R. Pfeiffer, "Superconducting transition temperatures of semiconducting $SrTiO_3$," *Phys. Rev. 163,* 380 (1967).

[150] P. J. Stiles, L. Esaki, and J. F. Schooley, "Observation of the superconducting energy gap in a semiconductor (GeTe)," *Phys. Lett.* **23**, No. 3, 206-207 (1966).

High-Temperature Radiation Thermometry and Radiometry

A new stable and inexpensive temperature reference at 1083 °C was developed by Richard D. Lee, using NBS copper standard samples and a carefully designed furnace. The copper sample was incorporated into a blackbody-type radiation source that was capable of stability at the level of 0.01 °C.[151]

Lee and and his colleague Ernest Lewis, Jr., determined the radiance temperatures at a wavelength of 650 nm displayed by 20 different graphite electrodes used in an electric arc . All of the electrode temperatures fell in the range 3786 K to 3808 K. The estimated uncertainty of the measurements was ±2 K.[152]

Lee also wrote a major paper describing the newly developed NBS photoelectric pyrometer and its use to realize the international temperature scale with enhanced accuracy.[153] At the level of 95 % confidence, the experimental uncertainties were ±0.12 °C at 1063 °C, ±0.24 °C at 1256 °C, and ±3 °C at 3525 °C.

Albert T. Hattenburg determined the spectral radiance of the anode of a low-current graphite arc in the region 210 nm to 850 nm. In performing these measurements, Hattenburg utilized a recently developed spectroradiometer of improved accuracy.

The radiance values showed an uncertainty estimated as 1.5 % to 5 %, with the smaller uncertainty at the longer wavelengths.[154]

Donald A. McSparron, Charles A. Douglas, and Herbert L. Badger of the Metrology Division reviewed available radiometric methods for measuring the output of pulsed lasers. They recommended use of a thermopile or phototube, as well as attenuating the laser power to a value similar to the calibrating source. The total uncertainty for the measurements was estimated to be 5 %.[155]

A new tungsten-filament lamp standard for total irradiance was brought into service. It replaced the type of 50 W carbon-filament lamp that had been in use for 50 years. The new lamps were made available in 100 W, 500 W, and 1000 W units. They operated at higher temperatures than the previous standard lamps, producing sources of considerably higher irradiance. The new lamps were prepared in a collaborative effort by Ralph Stair of the Metrology Division, in collaboration with William E. Schneider, and William B. Fussell.[156]

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[151] R. D. Lee, "Construction and operation of a simple high-precision copper-point blackbody and furnace," *NBS Technical Note 483*, May 1969. 16 pp.

[152] R. D. Lee and E. Lewis, "Radiance temperature at 6500 Å of the graphite arc," *Appl. Opt.* **5**, No. 11, 1858 (1966).

[153] R. D. Lee, "The NBS photoelectric pyrometer and its use in realizing the International Practical Temperature Scale above 1063 °C," *Metrologia* **2**, No. 4, 150-162 (1966).

[154] A. T. Hattenburg, "Spectral radiance of a low current graphite arc," *Appl. Opt.* **6**, No. 1, 95-100 (1967).

[155] D. A. McSparron, C. A. Douglas, and H. L. Badger, "Radiometric methods for measuring laser output," *NBS Technical Note 418,* November 1967.

[156] R. Stair, W. E. Schneider, and W. B. Fussell, "The new tungsten-filament lamp standards of total irradiance," *Appl. Opt.* **6**, No. 1, 101-105 (1967).

Joseph C. Richmond and Gerhart J. Kneissl, collaborating with their colleagues Douglas L. Kelley and F.J. Kelly of the Institute of Applied Technology, reported new procedures for the precise determination of total normal emittance of ceramic materials at very high temperatures.[157]

Kneissl and Richmond also reported the construction and testing of an integrating sphere for use with laser light sources. Using the new equipment, they were able to measure the reflectance of a variety of refractory materials to 2150 °C, with an imprecision less than 0.05 %.[158]

Gerhart J. Kneissl obtained reflectance measurements from the laser-source reflectometer. The laser beam was alternately directed into a large integrating sphere (outside picture at left) and a small averaging sphere (left center). Reflectance values were indicated by a digital voltmeter.

[157] J. C. Richmond, G. J. Kneissl, D. L. Kelley, and F. J. Kelly, "Procedures for precise determination of thermal radiation properties," *NBS Technical Note 292*, February 1967.

[158] Gerhart J. Kneissl and Joseph C. Richmond, "A Laser-Source Integrating Sphere Reflectometer," *NBS Technical Note 439*, February 1968.

In a related work, William Fussell and Jon C. Geist measured the normal spectral emissivity of single-crystal calcium fluoride in the wavelength range 2 μm to 12 μm and the temperature range 500 °C to 600 °C.[159]

Thermodynamic Properties of Materials

Thomas B. Douglas calculated the high-temperature energies of dilute solid solutions for all 96 cases of binary alkali halides excepting cesium.[160] His results compared favorably with available experimental data.

In the area of statistical physics, Raymond D. Mountain reviewed a comprehensive calculation of the interaction of light with density fluctuations in a dense, simple fluid.[161] In the calculation, Mountain used the hydrodynamic equations of irreversible thermodynamics; he was able to confirm the results of Landau and Placzek and to develop a procedure for deriving certain correction terms as well.

Melville S. Green and his colleague Leopold S. Garcia-Colin of the Mexican National Commission for Nuclear Energy analyzed the meaning of temperature in the kinetic theory of dense gases.[162] These ideas were related to the general question of useful macroscopic variables in non-equilibrium statistical mechanics.

Critical phenomena in a variety of materials—gases, binary liquids, binary alloys, magnets, and superfluids—were compared by Jan V. Sengers and Johanna M. H. L. Sengers for the journal *Chemical and Engineering News.*[163] They found strong similarities in the thermodynamic behavior among these very different systems. It was their hope to obtain a universal equation of state for all critical anomalies.

High-Speed Measurements

A lengthy discussion on the use of the exploding-wire technique to provide information on the high-temperature properties of a variety of materials was presented by Esther C. Cassidy, Stanley Abramowitz, and Charles W. Beckett in NBS Monograph No. 109, issued in November 1968. Time-resolved measurements of electrical energy,

[159] W. B. Fussell and J. C. Geist, "Approximate normal emissivity spectra in the infrared at elevated temperatures of single-crystal and polycrystalline calcium fluoride," *Appl. Opt.* **6**, No. 1, 119-124 (1967).

[160] T. B. Douglas, "Calculated heats of dilute solid solution among the alkali halides other than cesium salts," *J. Chem. Phys.* **45**, No. 12, 4571-4585 (1966).

[161] R. D. Mountain, "Spectral distribution of scattered light in a simple fluid," *Revs. Mod. Phys.* **38**, No. 1, 205-214 (1966).

[162] L. S. Garcia-Colin and M. S. Green, "Definition of temperature in the kinetic theory of dense gases," *Phys. Rev.* **150** No. 1, 153-158 (1966).

[163] J. V. Sengers and J. M. H. L. Sengers, "The critical region," *Chem. Eng. News* **46**, No. 25, 104-118 (1968).

power, voltage and current; high-speed photographs of the explosions; and time-dependent recordings of the radiant output of the sample all were described, along with notes on the types of apparatus available.[164] This technique would later be exploited by a group led by Ared Cezairliyan for the study of refractory metals.

Computing Devices

With the collaboration of Robert C. Thompson of the Office of Standard Reference Data, Charles H. Popenoe prepared a recipe for simple modifications to a teletypewriter to facilitate its use as a remote console for a computer.[165] This work led to pioneering developments in computer-assisted typesetting, led by Joseph Hilsenrath, Robert C. Thompson, and Carla G. Messina.

Atomic Physics Division (Karl G. Kessler, Chief).

The Atomic Physics Division was composed of 6 sections: spectroscopy, headed by William C. Martin; infrared and microwave spectroscopy, under David R. Lide, Jr.; far-ultraviolet physics, led by Robert P. Madden; electron physics, under John A. Simpson; atomic physics, headed by Richard D. Deslattes; and plasma spectroscopy, under Wolfgang L. Wiese.

Atomic Spectroscopy

One of the most important contributions of the Bureau's Atomic Physics Division was the observation, analysis, and tabulation of spectral lines arising from the excitation of neutral and ionized atoms. William F. Meggers, a world-renowned spectroscopist, was heavily involved in this work from 1914 until the year of his death in 1966. In recognition of his painstaking and prolific contributions to the knowledge of atomic spectra during a half-century at NBS, an entire issue of the NBS Journal of Research (Vol. **71A**, No. 6, 1967) was dedicated to Meggers' work. In an introductory tribute to the work of Meggers, Division Chief Karl Kessler wrote, "More than any other man, Dr. Meggers came to be identified with this voluminous increase in our knowledge of atomic structure."

Kessler's tribute was followed by a paper describing Meggers' last work, on the second spectrum of ytterbium (Yb II);[166] Charlotte E. Moore-Sitterly, one of his long-time colleagues, edited the 148-page paper which analyzed spectra involving some 315 energy levels. In the same issue, a second Meggers work, accomplished jointly with William R. Bozman, Charles H. Corliss, and Jack L. Tech, presented a new description of the spectrum of Tc I and Tc II. Corliss and Tech also discussed the

[164] E. C. Cassidy, S. Abramowitz, and C. W. Beckett, "Investigation of the exploding wire process as a source of high temperature studies," *NBS Monograph 109*, November 1968, 53 pp.

[165] Charles H. Popenoe and Robert H. Thompson, "Accessory Equipment and Teletypewriter Modifications for Remote Computer Consoles," *NBS Technical Note 419*, February 1968.

[166] In the standard notation used in the spectroscopy of atoms, Tc II refers to the "second spectrum" of technetium, i.e., the spectrum of the singly ionized atom. In this notation, Tc I refers to neutral Tc, Tc III to doubly ionized Tc, and so on. See, for example, P. H. Heckmann and E. Träbert, *Introduction to the Spectroscopy of Atoms*, translated from the German by S. Bashkin (New York: North-Holland, 1989) p. 10.

Spectroscopist William F. Meggers adjusted interferometer for use with the ^{198}Hg lamp, which he developed in 1947. Although the 86 Kr lamp became the international standard in 1960, the ^{198}Hg lamp was frequently used for laboratory length measurements because of its relative ease of operation.

lifetimes of energy levels, oscillator strengths, and transition probabilities in neutral Fe (some of this material appeared in NBS Monograph 108, March 1968); Corliss and John B. Shumaker, Jr. of the Heat Division, measured transition probabilities in Ar I; Victor Kaufman and Jack Sugar observed a dozen spectral lines in Pr V; and Joseph Reader and Sumner P. Davis (on leave from the University of California, Berkeley) examined the fundamental energy levels of Pm I.

Spectroscopic instrumentation specifically designed for use with the NBS 180 MeV electron synchrotron was described by Robert P. Madden, David L. Ederer, and Keith Codling.[167] These instruments included a 3 m grazing-incidence spectrograph and a monochromator.

Richard Deslattes, working with William Sauder of the Virginia Military Institute, completed a study of the Zeeman effect in the annihilation of positronium.[168] With Robert E. LaVilla, Deslattes also described the spectra obtained from several

[167] R. P. Madden, D. L. Ederer, and K. Codling, "Instrumental aspects of synchrotron XUV spectroscopy," *Appl. Opt.* **6**, No. 1, 31-38 (1967).

[168] W. C. Sauder and R. D. Deslattes, "Zeeman effect in positronium annihilation at low temperatures," *J. Res. NBS* **71A**, No. 5, 347-353 (1967).

chlorinated hydrocarbons, using a two-crystal x-ray spectrometer with high resolving power.[169]

John A. Simpson described the physical limitations on electron beams and the design of electron guns in one chapter of the text *Methods of Experimental Physics* and the production and use of monoenergetic electron beams in another.[170]

In collaboration with Elio Passaglia, Chief of the Metallurgy Division, and Nicholas N. Winogradoff of the Electronic Technology Division, Karl G. Kessler, Chief of the Atomic Physics Division, prepared a summary of NBS laser standards and materials projects supported by either the Advanced Research Projects Agency or the U.S. Air Force Avionics Laboratory.[171] The projects included the following: laser energy and power measurement and continuous-wave power measurements, by Donald A. Jennings;[172] laser pulse measurements, continuous-wave power measurements, and radiometric techniques at new laser wavelengths, by Donald McSparron of the Metrology Division; CO_2 laser power measurements, by Louis J. Schoen; laser power and energy measurements, properties of long-wavelength lasers, and semiconductor laser materials, by Nicholas Winogradoff; far- and near-field laser studies, by Merritt M. Birky; bulk optical properties of laser materials, by Given W. Cleek of the Inorganic Materials Division; laser characterization standards, by John L. Torgeson, also of the Inorganic Materials Division; optical evaluation of laser rods, by Fred W. Rosberry of the Metrology Division; magnetic resonance studies of laser materials, by Te-Tse Chang of the Inorganic Materials Division; laser-rod holography, by Klaus D. Mielenz and Arthur T. Funkhouser, both of the Metrology Division; and optical characterization of crystals, by Robert F. Blunt and Martin I. Cohen, both of the Inorganic Materials Division.

Office of Deputy Director, IBS/Boulder (Bascom W. Birmingham, Acting Chief).

In 1968 all the activities at the Boulder site were brought under the supervision of one manager, who in turn reported to the Director of IBS. By that time, the NBS Central Radio Propagation Laboratory already had been transferred to the Environmental Science Services Administration—another unit of the Department of

[169] R. D. Deslattes and R. E. LaVilla, "Molecular emission spectra in the soft x-ray region," *Appl. Opt.* **6**, No. 1, 39-42 (1967). On the basis of this and related atomic constants work utilizing x-rays and optical interferometry, Deslattes received the 1969 Arthur S. Flemming Award. The Flemming Award was given to outstanding government researchers under the age of 40.

[170] J. A. Simpson, "Electron guns," and "Special sources of monoenergetic electrons," in a Chapter entitled "Sources of Atomic Particles" in *Methods of Experimental Physics*, Volume *4*, "Atomic and Electron Physics," pp 84-95 (New York: Academic Press, Inc., 1967) pp. 84-95 and 124-135.

[171] K. G. Kessler, E. Passaglia, and N. N. Winogradoff, editors, "Research on laser standards and materials at the National Bureau of Standards," *NBS Technical Note 449,* June 1968, 32 pp.

[172] See, for example, D. A. Jennings, E. D. West, K. M. Evenson, A. L. Rasmussen, and W. R. Simmons, "Laser power and energy measurements," *NBS Technical Note 382,* October 1969, 64 pp.

Commerce—although the personnel involved still occupied part of the NBS/Boulder Radio Building. Five technical divisions and three administrative divisions made up the Boulder laboratories.

Administrative Services Division/Boulder (Barton F. Betts, Chief).

The Instrument Shops Division at Boulder under R. S. Perrill and the Plant Division at Boulder headed by E. A. Yuzwiak rendered services that were similar to those of their counterparts in Gaithersburg. Their personnel contracted for materials and equipment, performed mail deliveries and managed other communications activities, provided the Boulder staff with visual aids and graphics, maintained records, constructed specialized scientific equipment, and cared for buildings and grounds.

Radio Standards Physics Division/Boulder (Harold S. Boyne, Acting Chief).

This division was composed of three sections: solid state electronics, under Robert J. Mahler; quantum electronics, headed by Donald A. Jennings; and plasma physics, led by Karl-Birger Persson.

Calibration Services

Calibration of certain electromagnetic properties of materials was offered by the RSP division. These properties included the permittivity of nonmagnetic liquids and solids, the permittivity of ferrites, magnetic permeability of toroids and rods, and ferromagnetic-resonance linewidths and gyromagnetic ratios of samples of various geometric shapes.

Laser Studies

A first for the Boulder laboratories—a pulsed ruby laser—was achieved by Donald A. Jennings in 1962.[173] The laser, powered by xenon flash lamps, was "bootlegged," according to Snyder and Bragaw, since no funds had been included in the Division budget for its construction. The new instrument made accessible a whole range of experiments that had been beyond the laboratory capabilities. It was also the forerunner of many other lasers, developed at Boulder and Gaithersburg, and of laser-characterization methods.

In 1968, an HCN laser was used to observe electron-paramagnetic-resonance absorption between two ground-state levels of oxygen. The laser-based spectrometer was constructed and used by a group that included Kenneth M. Evenson, Joseph S. Wells, and Robert J. Mahler from the Radio Standards Division, Herbert P. Broida—famous

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[173] Wilbert F. Snyder and Charles L. Bragaw, "Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards," (Washington, DC: USGPO, 1986): p 631. Jennings received the Department of Commerce Gold Medal Award for Exceptional Service in 1970 for this work.

for his contributions to the NBS free radicals program but then on his way to the University of California at Santa Barbara—and Masataka Mizushima of the University of Colorado.[174]

Material Properties

The accurate and convenient measurement and comparison of the complex permeability of magnetic materials in the range 30 MHz to 100 MHz were discussed by A. L. Rasmussen and his colleague from the Radio Standards Engineering Division, C. McKay Allred.[175] The manner by which an admittance meter could be used for this purpose was described in some detail.

William S. Lovell and Lynn M. Thiel discussed interferometric methods for the determination of the complex dielectric constants of liquids; in addition, they pointed out sources of error in these methods.[176]

Spectroscopy Data Compilation

During 1968, Volumes IV and V of Monograph 70, *Microwave Spectral Tables,* were published by Marian S. Cord, Jean D. Peterson, Matthew S. Lojko, and Rudolph H. Haas. Volume IV, containing some 400 pages, was devoted to a compilation of literature values up to 1961 for the spectra of polyatomic molecules without internal rotation. Volume V, about 25 % larger, contained a listing of the spectral lines given in Vols. I, II, and III. Monograph 70 had been initiated as a service to the user community by Paul F. Wacker in 1964. It expanded upon the first atlas of microwave spectra, *NBS Circular 518,* published in 1952 by P. Kisliuk and C. H. Townes.

Electromagnetic Fields

In a study of the radial distribution of radiation from a cylindrical source, Earl R. Mossburg, Jr., and Matthew S. Lojko used orthogonal polynomial expansions to solve the Abel integral transform.[177]

Radio Equipment

Noting the need for regulated, low-voltage power supplies for use with transistorized circuits, John H. Rogers offered three different circuit designs for such supplies.[178] The designs differed principally in the available circuit gain.

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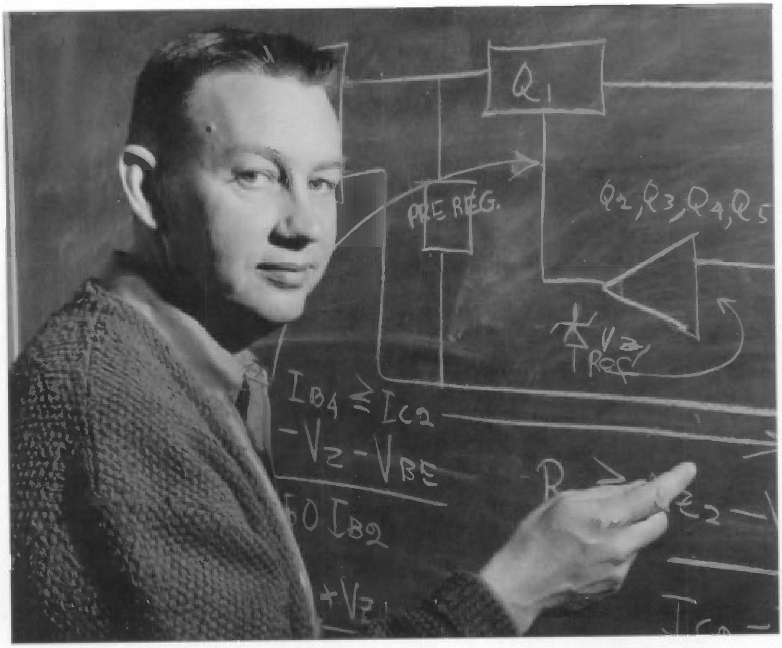
[174] K. M. Evenson, H. P. Broida, J. S. Wells, R. J. Mahler, and M. Mizushima, "Electron paramagnetic resonance absorption in oxygen with the HCN laser," *Phys. Rev. Lett.* **21**, 1038-1040 (1968).

[175] A. L. Rasmussen and C. M. Allred, "An admittance meter technique to measure the complex permeability at VHF," *J. Res. NBS* **72C**, No. 1, 81-89 (1968).

[176] W. S. Lovell and L. M. Thiel, "Interferometric Measurements of the Complex Dielectric Constant of Liquids," *NBS Technical Note 369,* August 1968.

[177] Earl R. Mossburg, Jr. and Matthew S. Lojko, "Solution of the Abel Integral Transform for a Cylindrical Luminous Region With Optical Distortions at Its Boundary," *NBS Technical Note 368,* July 1968.

[178] John H. Rogers, "Transistorized Low Voltage Regulator Circuits and Design," *NBS Technical Note 371,* September 1968.



In 1968, John H. Rogers prepared a schematic diagram from simplified design equations for low-voltage regulator circuits. The equations led to the construction of inexpensive and dependable regulator circuits.

Radio Standards Engineering Division/Boulder (Helmut M. Altschuler, Chief).

The RSED conducted research in the following areas: radiofrequency electrical standards, under C. McKay Allred; radiofrequency impedance standards, ordinarily headed by Robert C. Powell but temporarily in the charge of Cletus A. Hoer; microwave circuit standards, under M. B. Hall; and electromagnetic field standards, led by Ramon C. Baird.

Calibration Services

The division offered calibrations of radiofrequency standard instruments used for measurements of voltage, power, impedance, attenuation, phase shift, effective noise temperature, pulse properties, and electromagnetic field strengths. Karl W. Wendt and Roy E. Larson were in charge of the calibration services.[179]

George E. Schafer described for the journal Proceedings of the IEEE the system of electromagnetic measurements in the United States, using Huntoon's national measurement system as a model.[180]

[179] "Calibration and Test Services of the National Bureau of Standards," *NBS Special Publication 250,* 1968.

[180] G. E. Schafer, "A systems concept of electromagnetic measurements in the U.S.A.," *Proc. IEEE* **55**, No 6, 775-778 (1967).

AC Current Standards

In connection with the Gaithersburg Electricity Division, we already have mentioned a study of alternating current standards by Winston W. Scott, Jr. and Nolan V. Frederick of the Radio Standards Engineering Division in Boulder. In this case, however, the comparisons involved current measurements at the higher frequencies utilized in radio work. Scott and Frederick focused on state-of-the-art techniques, including thermocouple ammeters, electrodynamic ammeters, photoammeters, and air-thermometer ammeters. The study emphasized frequency ranges, current-level ranges, and convenience as much as it did the accuracy of the methods.[181]

Allan S. Risley and Howard E. Bussey reported studies indicating success with calculations on nonresonant circuits modeled using resonant-circuit theory.[182]

Measurement Techniques

Progress in an international intercomparison of electromagnetic measurements at high frequencies—from 30 kHz to 40 GHz—were reported by Myron C. Selby.[183] Besides NBS, other international organizations involved in the project included the International Electrotechnical Commission, the International Radio Scientific Union and the International Bureau of Weights and Measures. At that time, measurements of power, attenuation, and permittivity already had been compared; the new objective was to standardize both measuring equipment and measurement procedures.

In a related effort, A. Y. Rumfelt and Lyman B. Elwell reviewed bolometric, calorimetric, and other types of radio-frequency power measurements, emphasizing techniques for minimizing error from mismatch, dc substitution, and bolometer-mounting inefficiency.[184] An error analysis in the use of a Wollaston-wire element in bolometers (a device known as a barretter) was outlined as well, by Stephen Jarvis, Jr., and John W. Adams.[185]

Donald N. Homan showed how parasitic loop currents in ac bridge circuits could be suppressed by the use of coaxial choke coils.[186] This technique soon became standard practice.

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[181] Winston W. Scott, Jr. , and Nolan V. Frederick, "The measurement of current at radio frequencies," *Proc. IEEE*, **55**, No. 6, pp. 886-891 (1967).

[182] A. S. Risley and H. E. Bussey, "Interpretation of ferromagnetic resonance measurement made in a nonresonant system," *IEEE Trans. Instr. Meas.* **IM-5**, No. 4, 393-396 (1966).

[183] M. C. Selby, "International comparison of measurements at high frequencies," *IEEE Spectrum* **3**, No. 1, 89-98 (1966).

[184] A. Y. Rumfelt and L. B. Elwell, "Radio frequency power measurements," *Proc. IEEE* **55**, No. 6, 837-850 (1967).

[185] S. Jarvis, Jr. and J. W. Adams, "Calculation of substitution error in barretters," *J. Res. NBS* **72C**, No. 2, 127-237 (1968).

[186] D. N. Homan, "Applications of coaxial chokes to ac bridge circuits," *J. Res. NBS* **72C**, No. 2, 161-165 (1968).

Microwave Attenuation

Robert W. Beatty, scientific consultant to division chief Helmut Altschuler, described microwave attenuation measurements and standards in NBS Monograph 97.[187] Ramon L. Jesch and Robert M. Jickling outlined the principles of impedance measurements for coaxial waveguides.[188]

Time and Frequency Division/Boulder (James A. Barnes, Chief).

James L. Jesperson was in charge of one of the division's three sections, frequency and time dissemination research; Donald W. Halford led another, atomic frequency and time standards. Peter P. Viezbicke headed the time and frequency broadcast services.

Calibration Services

Most of the services concerning NBS time and frequency were delivered via the broadcast signals from radio stations WWV, WWVL, WWVB, and WWVH. These signals included standard radio frequencies, standard audio frequencies, standard musical pitch, standard time intervals, time of day, universal time (UT2) corrections, radio propagation forecasts, and geophysical alerts. NBS Special Publication 236, *NBS Frequency and Time Broadcast Services*, issued in 1968, provided a brief discussion of these services. However, the division also offered an in-house frequency-calibration service involving direct comparison of the user's signal source with the NBS Frequency Standard.

Alvin H. Morgan reviewed the distribution of the standard time and frequency signals in a paper prepared for the *Proceedings of the IEEE.*[189]

A New International Unit of Time

As a result of research performed over the previous several years, much of it at NBS, the 13th General Conference on Weights and Measures was able to adopt a new definition of the second. The new definition was: "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two nuclear hyperfine levels of the fundamental state of the atom of cesium-133." Heavily involved in the research that led to the new definition were James Barnes and David W. Allan.[190]

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[187] R. W. Beatty, "Microwave measurements and standards," *NBS Monograph 97*, April 1967.

[188] R. L. Jesch and R. M. Jickling, "Impedance measurements in coaxial waveguide systems," *Proc. IEEE* 55, No. 6, 912-923 (1967).

[189] A. H. Morgan, "Distribution of standard frequency and time signals," *Proc. IEEE* 55, No. 6, 827-836 (1967).

[190] J. A. Barnes and D. W. Allan, "An approach to the prediction of coordinated universal time," *Frequency*, 5, No. 6, 15-20 (1967).

Frequency Standards

David Allan also published a theoretical treatment on the statistics of frequency standards based on atomic transitions.[191] The work established a relationship between the expectation value for the standard deviation of the frequency fluctuations of short-term data samples and the infinite-duration standard deviation. It also included methods for determining the power spectral density of the frequency fluctuations, the sampling time, and the dependence on system bandwidth.

In a cooperative study involving the NBS Time and Frequency Division, the Quantum Electronics Division of Varian Associates, and the Hewlett-Packard Co, an intercomparison was completed for hydrogen and cesium frequency standards. These standards included the NBS III cesium-beam United States Frequency Standard, a cesium-beam device from Hewlett-Packard, and two hydrogen masers built by Varian Associates.[192] The group found that the level of stability exhibited by the two hydrogen masers reached 1×10^{-13} over a two-month period. The other devices showed similar levels of stability. The frequency of the atomic transition in hydrogen observed during the work, corrected to conditions of free space, zero magnetic field, and zero absolute temperature was (1420,405,751.7860 ± 0.0046) Hz.

Flicker Noise

The subject of flicker noise—random noise occurring in electrical circuits, whose spectral density is larger at lower frequencies—was treated by Donald Halford. He developed a general mechanical model for frequency-dependent noise.[193] This topic had been treated earlier by Barnes and Allan, using the method of fractional order of integration.[194]

Laboratory Astrophysics Division/Boulder (Lewis M. Branscomb, Chief).

The Laboratory Astrophysics Division served as the "home" for NBS staff members working at the Joint Institute for Laboratory Astrophysics (JILA). The brainchild of Lewis Branscomb and Richard N. Thomas, JILA was established in 1962 on the campus of the University of Colorado at Boulder. The LAD/JILA group quickly became known within NBS as a fertile source of scientific achievement in aerospace physics. The intimate connection with the graduate program of the University of Colorado provided an abundant supply of eager scientific collaborators. Branscomb was the first LAD chief.

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[191] D. W. Allan, "Statistics of atomic frequency standards," *Proc. IEEE* **54**, No. 2, 221-230 (1966).

[192] R. Beehler, D. Halford, R. Harrach, D. Allan, D. Glaze, C. Snider, J. Barnes, R. Vessot, H. Peters, J. Vanier, L. Cutler, and L. Bodily, "An intercomparison of atomic standards," *Proc. IEEE* **54**, No. 2, 301-302 (1966).

[193] D. Halford, "A general mechanical model for $|f|^{\alpha}$ spectral density random noise with special reference to flicker noise $1/|f|$," *Proc. IEEE* **56**, No. 3, 251-258 (1968).

[194] J. A. Barnes and D. W. Allan, "A statistical model of flicker noise," *Proc IEEE* **54**, No. 2, 176-178 (1966).

Laser Technology

Laser technology became one of the first major efforts in a collaboration that linked scientists from several divisions. As noted previously, Donald A. Jennings, Chief of the Quantum Electronics Section of the Radio Standards Physics Division, built the first laser at the Boulder site. John L. Hall, who came to the Bureau as a Postdoctoral Research Associate, received the Department of Commerce Gold Medal Award in 1970 for his exceptional research on lasers and their application to length metrology. Details of laser collaborations appear in later chapters.

Wolf-Rayet Stars

A small (38 participants) symposium on Wolf-Rayet stars was held at the University of Colorado June 10-14, 1968. The symposium was co-sponsored by the American Astronomical Society, the Harvard College Observatory, JILA, and the Smithsonian Astropysical Observatory. Katharine B. Gebbie and Richard N. Thomas edited the proceedings.[195] An interesting feature of the 275-page proceedings is that an enormous amount of astronomical effort up to that time had apparently produced relatively few widely held conclusions regarding an interesting group of radiating celestial objects.

Electron Scattering in Stars

The importance of Doppler noncoherence in electron scattering in particular types of stars was discussed by David Hummer and D. Mihalas in the *Astrophysics Journal.*[196]

In a study of excitation of light atoms, Robert L. Long, Jr., Donald M. Cox, and Stephen J. Smith reported an investigation of the excitation of the 2p state of atomic hydrogen by electron impact.[197] The results confirmed the existence of a substantial discrepancy between theoretical predictions and experimental findings at electron energies below 50 eV.

Branscomb, the Division Chief, described his study of photodetachment of the negative hydroxyl ion,[198] and summarized the progress in electron atomic and molecular physics over the previous two decades.[199]

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[195] Katharine B. Gebbie and Richard N. Thomas, editors, "Wolf-Rayet Stars" in *Proceedings of a Symposium Held at the Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, CO, June 10-14, 1968*, NBS Special Publication 307, December 1968, 275 pp.

[196] D. G. Hummer and D. Mihalas, "Line formation with noncoherent electron scattering in O and B stars," *Astrophys. J.* **150**, No. 1, L57-L59 (1967).

[197] R. L. Long, Jr. , D. M. Cox, and S. J. Smith, "Electron impact excitation of hydrogen Lyman-α radiation," *J. Res. NBS* **72A**, No. 5, 521-535 (1968).

[198] L. M. Branscomb, "Photodetachment cross section, electron affinity, and structure of the negative hydroxyl ion," *Phys. Rev.* **148**, No. 1, 11-18 (1966).

[199] L. M. Branscomb, "Twenty years of physics: atoms, molecules, and electrons," *Physics Today* **21**, No. 5, 36-39 (1968).

Cryogenics Division/Boulder (Dudley B. Chelton, Acting Chief).

Members of the Cryogenics Division participated in nearly every major U.S. cryogenic engineering program from the time of its founding. Of particular importance to America's space effort was the division's studies of the thermodynamic properties of fluids, in the early days directed by Robert J. Corruccini.

The Division provided many services to the cryogenics community in 1968. The Cryogenic Data Center, headed by Victor J. Johnson, collected low-temperature-properties information on materials of interest to both engineers and scientists. Other division work featured research on cryogenic properties of solids—headed by Richard H. Kropschot—and fluids, under the temporary leadership of Duane L. Diller. Research on fluid-transport systems was led by R. V. Smith, and cryogenic systems research was headed by R.W. Arnett on an acting basis. Cryogenic metrology was the specialty of a group led by Douglas B. Mann. W. A. Wilson headed a group offering cryogenic technical services.

Thermal Properties

The kinetic-theory approach to transport-property calculations for dilute gases was employed by Howard J. M. Hanley and Gregory E. Childs to derive values for the coefficients of viscosity and thermal conductivity of dilute nitrogen and oxygen[200] and, in a separate *NBS Technical Note,* of dilute neon, krypton, and xenon.[201] In this context, the term 'dilute' reflected the temperature-dependent choice of a typical interatomic spacing, chosen with a particular calculational method in mind.

During the 10th International Conference on Low Temperature Physics, held in Moscow in 1966, John J. Gniewek, John C. Moulder, and Richard H. Kropschot reported measurements of the electrical conductivity of copper single crystals and polycrystalline wire in the temperature range from 4 K to 77 K.[202] Resistivity ratios (273 K/4 K) exceeded 3×10^4 and 1×10^4, respectively. In a related effort, L. A. Hall reported results of a survey of electrical resistivity measurements on 16 pure metals in the range 0 K to 273 K.[203] Graphs illustrating the differences between samples of varying size and purity were included.

Integrated tables of pressure, volume, and temperature, from the triple point to the critical point of saturated liquid oxygen, nitrogen, argon, and parahydrogen, were presented by Hans M. Roder, Robert D. McCarty, and Victor J. Johnson.[204]

200 G. E. Childs and H. J. M. Hanley, "The viscosity and thermal conductivity coefficients of dilute nitrogen and oxygen," *NBS Technical Note 350,* October 1966.

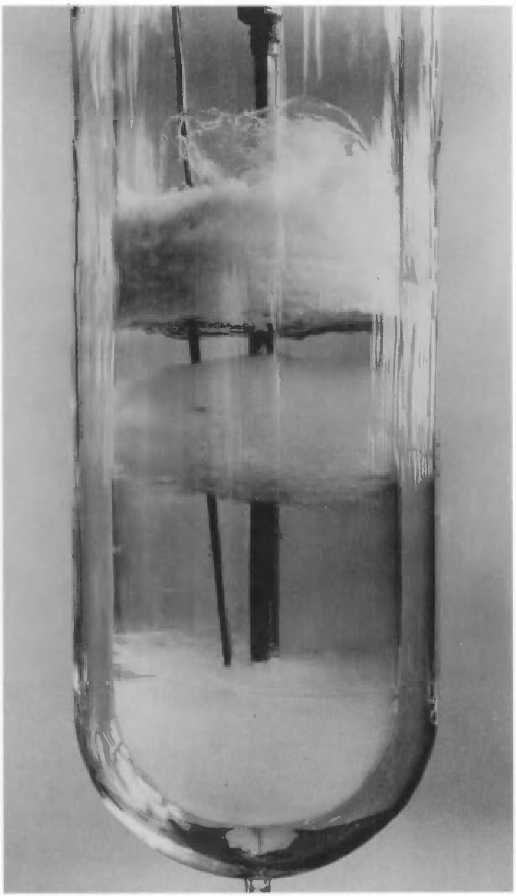
201 H. J. M. Hanley and G. E. Childs, "The viscosity and thermal conductivity coefficients of dilute neon, krypton, and xenon," *NBS Technical Note 352,* March 1967.

202 J. J. Gniewek, J. C. Moulder. and R. H. Kropschot, "Electrical conductivity of high purity copper," in *Proc. Tenth Intern. Conf. Low Temperature Physics, Moscow, USSR, Aug. 31-Sept. 9, 1966,* (Moscow, USSR: Viniti, 1967), pp. 366-370.

203 L. A. Hall, "Survey of electrical resistivity measurements on 16 pure metals in the temperature range 0 to 273 °K," *NBS Technical Note 365,* February 1968.

204 H. M. Roder, R. D. McCarty, and V. J. Johnson, "Saturated liquid densities of oxygen, nitrogen, argon, and parahydrogen," *NBS Technical Note 361,* January 1968. 70 pp.

In a study related to the needs of the National Aeronautics and Space Administration for data on liquid and solid hydrogen, David E. Daney, Paul R. Ludtke, Dudley B. Chelton, and Charles F. Sindt described certain physical properties of "slush" hydrogen, composed of partially frozen hydrogen of high enthalpy content.[205]



Slush hydrogen was formed at the bottom of this Dewar flask. Solid hydrogen, formed on the surface of liquid hydrogen, sank to the bottom and broke into very fine particles. This combination of liquid and very fine, solid particles of hydrogen—slush hydrogen—provided a desirable rocket fuel.

As a first step in the critical evaluation of the thermophysical properties of methane at low temperatures, L. A. Hall presented a bibliography of these properties selected for the temperature range 0 K to 300 K.[206] The bibliography contained more than 600 references.

[205] D. E. Daney, P. R. Ludtke, D. B. Chelton, and C. F. Sindt, "Slush hydrogen pumping characteristics," *NBS Technical Note 364*, April 1968.

[206] L. A. Hall, "A bibiography of thermophysical properties of methane from 0 to 300 °K," *NBS Technical Note 367*, May 1968.

Cryogenic Thermometry

Lawrence L. Sparks and Robert L. Powell described the results of a study of low-temperature thermocouple thermometers in the range 78 K to the ice point.[207] In this work, they produced tables of emf *vs* temperature, as well as typical levels of reproducibility.

Cryogenic Flow

In a study that also was related to the design of cryogenic fluid-transport equipment, James A. Brennan, D. K. Edmonds, and Raymond V. Smith recorded experimental results of two-phase, mass-limiting flow measurements on hydrogen and nitrogen.[208] The experimental data were compared to the results of simple analytical model calculations.

Design of Cryogenic Apparatus

Ray Radebaugh presented a complete and consistent set of data for the thermodynamic properties of liquid ^{3}He – ^{4}He solutions for the temperature range 0 K to 1.5 K.[209] The information was important for the optimization of the design of a novel, effective type of cryogenic refrigeration based on the injection of liquid ^{3}He into liquid ^{4}He in the region below 1 K. The so-called "^{3}He – ^{4}He dilution refrigerator" had been suggested by Heinz London in 1951, but only in 1966 had a successful model been built by Hall, Ford, and Thompson of the University of Manchester in the United Kingdom.

A detailed analysis of the performance of the type of refrigerator conceived in 1873 for use at much higher temperatures by George Brayton, a Boston engineer, was presented by R. C. Muhlenhaupt and T. Richard Strobridge.[210] The Brayton cycle had seen extensive use in aircraft cooling and was considered a good candidate for use in space-flight power systems. Muhlenhaupt and Strobridge discussed the use of nitrogen, parahydrogen, and helium as potential refrigerants. Some 75 tables of projected performance data were included in the note.

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[207] L. L. Sparks and R. L. Powell, "Cryogenic thermocouple thermometry," *Meas. Data* **1**, No. 2, 82-90 (1967).

[208] J. A. Brennan, D. K. Edmonds, and R. V. Smith, "Two-phase (liquid-vapor), mass-limiting flow with hydrogen and nitrogen," *NBS Technical Note 359,* January 1968.

[209] R. Radebaugh, "Thermodynamic properties of He^3–He^4 solutions with applications to the He^3–He^4 dilution refrigerator," *NBS Technical Note 362,* December 1967.

[210] R. C. Muhlenhaupt and T. R. Strobridge, "An analysis of the Brayton cycle as a cryogenic refrigerator," *NBS Technical Note 366,* August 1968.

Institute for Materials Research (John D. Hoffman, a theoretician in the field of polymer science, was appointed Director of IMR in 1968).

Whereas the mission of the Institute for Basic Standards was focused on the maintenance and creation of standards of physical measurement, that of the IMR was to assist and stimulate industry in the development of new and improved products by increasing the understanding of the relevant properties of useful materials; to develop criteria by which the performance characteristics of basic materials could be evaluated; and to create standard reference materials to facilitate measurement comparisons and tc aid in the control of production processes.

Office of Standard Reference Materials (Wayne W. Meinke, Chief).

The program in standard reference materials was one of the most successful of all Bureau activities. Even as an unofficial service, the program had benefited U.S. scienc and industry from 1905 by furnishing standard samples, standard materials, and reference materials. The activity had begun in response to a request from the Americar Foundrymen's Association for help in producing standard samples of cast iron to promote uniform analytical and manufacturing techniques.[211] In 1950, Congress amended the NBS enabling legislation—in part to create a more direct emphasis on standard reference materials. In 1964, the title Standard Reference Materials was given to a freshly integrated program and the OSRM was formed with Meinke as its head.

The official mission of the OSRM was to evaluate the requirements of science and industry for carefully characterized reference materials and to stimulate NBS efforts to create, produce, and distribute such materials. As a "matrix-management" office, the OSRM was substantially smaller than a technical division. J. Paul Cali served as Deputy Chief, John L. Hague was coordinator for research on inorganic standards, Robert E. Michaelis coordinated work on metallic standards, Thomas W. Mears was the coordinator for organic standards, Hugh F. Beeghly provided technical liaison, and Margaret E. Guggenheimer was the Administrative Officer. There were about a dozen other OSRM employees. Two were machinists, preparing samples; Herbert L. Carter and G. Eugene Deardorff. The others were administrative staff; Margaret E. Graury, Linda L. Grimes, James L. Izlar, Suzanne Chew Love, Ruth H. Meyer, William P. Reed, Mary H. Roth, Patricia E. Schmitz, Connie L. Stanley, Robert J. Stewart, and Leo F. Wright. Their responsibilities included preparing certificates, tracking funding and expenditures, interacting with the public, and preparing program information.

As a consequence of their many contributions to the Nation's technology, standard reference materials were one of the outputs of the Bureau that was easiest for the layman to understand.

[211] See "Measures For Progress," p. 93.

Standard Reference Materials (SRMs) were well-characterized materials that proved extremely useful in calibration programs or as references for the control of commercial or scientific processes. After preparation at the Bureau or elsewhere, SRMs were compared to NBS master standards and certified with respect to a particular characteristic. The NBS certification was provided as a quantity, with a numerical value and uncertainty limits that enabled the users to make comparisons with their own products rather than to perform absolute determinations of the characteristic, a far more challenging task.

In 1968, NBS Miscellaneous Publication 260, *Standard Reference Materials: Catalog and Price List of Standard Materials Issued by the National Bureau of Standards* provided a ready guide to the availability and cost of these materials. Over 650 different types of SRM's in 70 different categories were in production, in compositions as diverse as biological specimens, ceramics, chemicals, gases, metals, minerals, ore samples, polymers, and radioisotopes. These materials were used as references in such enterprises as aerospace, oceanography, pollution control, nuclear energy, medicine, and transportation, as well as in the manufacture of pharmaceuticals, plastics, glass, cement, steel, and non-ferrous metals.

The SRM program at the Bureau circa 1968 was partly self-supporting through sales of the individual units; the sales price of each unit was set so as to recover the cost to produce it. In 1968 some 43,000 units were sold to more than 4500 customers, returning just over $1 million to NBS to continue the program. Often a particular SRM was developed in the course of a project whose objective was essentially unrelated to the eventual use of the unit; demand for the standard from potential customers would then be satisfied by initiating a production project within NBS which would last until the demand was satisfied or until the reference standard might become available from a source outside the Bureau.

During 1968 more than 100 SRMs were introduced or renewed. Thirteen of the Bureau's technical divisions were involved in producing these standards. Among the new materials were the following:

- *SRM 911, Certified Purity Cholesterol.*

This standard, requested by the College of American Pathologists and the American Association of Clinical Chemists, provided a cholesterol reference of high purity, (99.4 ± 0.3) %, for laboratory comparisons. The purity was determined using several methods—gas chromatography; thin-layer chromatography; and mass, infrared, and nuclear magnetic resonance spectroscopy. The analyses were performed by Alex Cohen, David H. Freeman, Robert T. Leslie, Rolf A. Paulson, Charles B. Romain, and Robert Schaffer of the Analytical Chemistry Division and Connie L. Stanley of the Office of Standard Reference Materials.[212]

[212] Copies of the certificates that accompanied each shipment of SRMs were kept on file in the OSRM. The information given in this section came mostly from review of certificates in the files.

- *SRM 680 and 681, High-Purity and Doped Platinum.*

These standards were prepared as reference materials for the analysis of purified platinum, which was used in a variety of technical applications. The high-purity samples contained a total of only about 10 parts per million (ppm) by weight of oxygen or metallic impurities; each lot was certified as to impurity levels. The doped samples typically contained 2 ppm to 10 ppm each of a list of a dozen common impurities, again with the amounts in each lot certified. In this case, the samples were prepared by commercial laboratories, then tested both at NBS and at participating laboratories for impurity levels and homogeneity.

- *SRM 1621 and 1622, Sulfur in Residual Fuel Oil.*

About 16 % of the sulfur dioxide that appeared as an air pollutant in 1968 came from residual fuel oil. SRMs 1621 and 1622 were produced to provide references for the analysis of fuel oil for sulfur. They were prepared from commercial fuel oils with natural sulfur contents. Gravimetric analysis of the sulfur content showed values certified to be (1.05 ± 0.02) % and (2.14 ± 0.01) %. The analytic work was performed by Booker S. Carpenter, Rolf A. Paulson, and William P. Schmidt of the NBS Analytical Chemistry Division.

- *SRM 701b, Standard Light-Sensitive Papers.*

This standard was developed to evaluate the dosage of radiant energy of commercial carbon-arc lamps that were used to test textiles for fading on exposure to light. The papers used in the SRM were prepared at the NBS paper mill under the supervision of Donald G. Fletcher, then calibrated by Paul J. Shouse and Elio Passaglia of the Polymers Division, using a standard carbon arc.

- *SRM 114L, Surface Area of Portland Cement.*

This type of standard had been used for more than a quarter-century as a reference in cement manufacture. The mean particle diameter and the surface area per gram as determined by two commercially available instruments were certified by members of the NBS Building Research Division.

- *SRM 981, 982 & 983, Isotopic Standards for Lead.*

Isotopic abundance ratios of lead samples were used in measuring the age of rocks, meteorites, and mineral deposits—important information for geological work throughout the world. However, great accuracy in measurement of the ratios was required in order to achieve believable results. These three new SRMs allowed laboratory personnel to calibrate with suitable accuracy the instruments used in this type of geologic measurements, as well as satisfying the many other requirements for isotopic standards of lead.

The SRMs provided three different ratios of the lead isotopes of mass 204, 206, 207, and 208, with the atomic fraction of each isotope certified within 0.01 % or better (substantially better, for the geological-age projects mentioned above). Preparation and analysis were performed by Edward J. Catanzaro, Thomas J. Murphy, William R. Shields, and Ernest L. Garner of the Analytical Chemistry Division.

- *SRM 1010, Microscopy Resolution Test Charts.*

American industrial and governmental organizations spent nearly $300 million annually to preserve records on microfilm. To ensure that the records were of adequate quality, it was necessary to evaluate the resolving power of the filming system in several positions of the focusing field. This SRM, periodically renewed, provided test patterns for that purpose. The latest charts provided 26 patterns ranging from 1 to 18 cycles per mm. The samples were prepared in the Institute for Basic Standards.

Responsibilities of Other IMR Divisions

Apart from the Office of Standard Reference Materials, the divisions of the IMR shared several responsibilities, including the following:

- Conduct research on constants of chemistry and physics, on properties and structure of matter.
- Develop methods for the preparation, purification, and analysis of materials.
- Investigate fundamental phenomena of importance to science and industry, including the effects of extremes of temperature and pressure and of radiation.
- Assist in the development of standard testing methods for materials.
- Develop and produce standard reference materials.
- Provide advice to government, science, and industry on basic materials problems.

Analytical Chemistry Division (Wayne W. Meinke, Chief).

The Analytic Chemistry Division housed a wide range of research and service work in nine sections—radiochemistry, James R. DeVoe, chief; spectrochemistry, Bourdon F. Scribner, chief; electrochemistry, Roger G. Bates, chief; analytical coordination chemistry, Oscar Menis, chief; microanalysis, John K. Taylor, chief; mass spectrometry, William R. Shields, chief; organic chemistry, Robert Schaffer, chief; activation analysis, Philip D. La Fleur, chief; and separation and purification, David H. Freeman, chief.

Section Summaries

An excellent summary of the activities of the Analytical Chemistry Division in the area of spectrochemical analysis was prepared as an *NBS Technical Note.*[213] Technical

[213] "Spectrochemical Analysis Section: Summary of Activities, July 1967 to June 1968," Bourdon F. Scribner, editor, *NBS Technical Note 452*, January 1968.

areas covered in the summary included optical spectrometry, electron probe microanalysis, x-ray fluorescence spectrometry, spark-source mass spectrometry, and analysis of high-purity materials.

A similar synopsis, this time in the areas of gravimetry, titrimetry, spectrophotometry, spectrofluorometry, and the analysis of gases in metals, was published in *Technical Note 424.*[214]

Technical Note 429, edited by David H. Freeman, Chief of the Separation and Purification Section of the Analytical Chemistry Division, contained a discussion of the activities in that section in ion exchange, ultrapure reagents, purification techniques, and crystallization.[215]

Roger G. Bates, Chief of the Electrochemical Analysis Section, prepared a summary of work done in that area.[216] Types of projects covered included acidity measurements, solvent effects on electrolyte processes, standardization of ion-selective electrodes, equilibrium ionic systems, conductance and transport by electrolytes, and preparation and properties of solvents.

The activities of the Microchemical Analysis Section, headed by John K. Taylor, the "grand old man" of NBS who, on his retirement in 1986, had accumulated 57 years of continuous service with the Bureau, were summarized in NBS Technical Note 455.[217] Topics covered included gas analysis, polarographic analysis, coulometric analysis, electroanalytical measurements, and microscopic and classical microchemical analysis.

Progress in mass spectrometry and testing of a new mass spectrometer, the formation of a new chemistry group to perform precise analytical work, and results in that area were summarized by William R. Shields, Chief of the Analytical Mass Spectrometry Section.[218]

Section chief Robert Schaffer reviewed progress in the Organic Chemistry Section in carbohydrate synthesis, structure, and characterization; clinical chemistry; polycyclic air-pollutant properties; and standard reference materials.[219]

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[214] "Analytical Coordination Chemistry: Titrimetry, Gravimetry, Flame Photometry, Spectrophotometry, and Gas Evolution," Oscar Menis, editor, *NBS Technical Note 424,* January 1968.

[215] "Separation and Purification Section: Summary of Initial Activities, February 1966 through June 1967," David H. Freeman, editor, *NBS Technical Note 429,* February 1968. The summary is continued in Technical Note 459, December 1968.

[216] "Electrochemical Analysis Section: Summary of Activities, July 1967 to June 1968, Roger G. Bates, editor," *NBS Technical Note 453,* July 1968.

[217] "Microchemical Analysis Section: Summary of Activities, July 1967 to June 1968," John K. Taylor, editor, *NBS Technical Note 455,* October 1968.

[218] "Analytical Mass Spectrometry Section: Summary of Activities, July 1967 to June 1968," William R. Shields, editor, *NBS Technical Note 456,* November 1968.

[219] "Organic Chemistry Section: Summary of Activities, July 1967 to June 1968," Robert Schaffer, editor, *NBS Technical Note 457,* September 1968.

Isotopic Characterization

In a series of investigations of absolute isotopic abundance ratios of high-purity elements important to science and industry, Edward J. Catanzaro, Thomas J. Murphy, William R. Shields, and Ernest L. Garner reported mass-spectrometric evaluations of the isotopic abundance ratios for several types of carefully prepared elemental samples. One of these was magnesium; the natural abundance ratios $^{25}Mg/^{24}Mg$ and $^{26}Mg/^{24}Mg$ were found to be 0.12663 ± 0.00013 and 0.13932 ± 0.00026, respectively, at the level of 95 % confidence, yielding a new value of the atomic weight for Mg (based on $^{12}C = 12$) of 24.30497 ± 0.00044.[220] Another study focused on common lead, "equal-atom" lead, and "radiogenic" lead, important for geological dating.[221] Yet a third investigation, of terrestrial rubidium, established the abundance ratio $^{85}Rb/^{87}Rb$ = 2.59265±0.00170, indicating an atomic weight of 85.46776±0.00026, again at 95 % confidence.[222] The authors made particular efforts to calibrate the two mass spectrometers used in the study in order to provide absolute values. The isotopic lead mixtures were offered for sale through the Standard Reference Materials Program.

Chemical Synthesis

Alexander J. Fatiadi was clearly one of the more prolific writers among the chemists at the Bureau during this period. He published 10 papers by himself between 1966 and 1968, and several others in collaboration with colleagues. His forte was the synthesis and analysis of polycyclic, aromatic hydrocarbons of importance to air-pollution studies.[223, 224, 225]

Microanalysis

Kurt F. J. Heinrich completed development of a new technique for microanalysis that utilized scans with an electron microprobe x-ray emission spectrometer.[226] The new method was expected to be particularly useful where spatial relationships were important. Heinrich also wrote a description of the principles and techniques of

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220 E. J. Catanzaro, T. J. Murphy, E. L. Garner, and W. R. Shields, "Absolute isotopic abundance ratios and atomic weight of magnesium," *J. Res. NBS* **70A**, No. 6, 453-458 (1966).

221 E. J. Catanzaro, T. J. Murphy, W. R. Shields, and E. L. Garner, "Absolute isotopic abundance ratios of common, equal-atom and radiogenic lead isotopic standards," *J. Res. NBS* **72A**, No. 3, 261-267 (1968).

222 E. J. Catanzaro, T. J. Murphy, E. L. Garner, and W. R. Shields, "Absolute isotopic abundance ratio and atomic weight of terrestrial rubidium," *J. Res. NBS* **73A**, No. 5, 511-516 (1969).

223 A. J. Fatiadi, "Preparation and purification of some oxidation products of perylene," *J. Res. NBS* **72A**, No. 1, 39-47 (1968).

224 A. J. Fatiadi, "Periodic acid, a novel oxidant of polycyclic, aromatic hydrocarbons," *J. Res. NBS* **72A**, No. 4, 341-350 (1968).

225 A. J. Fatiadi, "Effects of temperature and of ultraviolet radiation on pyrene adsorbed on garden soil," *Envir. Sci. Tech.* **1**, No. 7, 570-572 (1967).

226 K. F. J. Heinrich, "Scanning electron probe microanalysis," *NBS Technical Note 278*, February 1967.

electron-microprobe analysis for the book *Advances in Materials Research.* [227] The subject "Quantitative Electron Probe Microanalysis" was the topic of a two-day seminar featuring a baker's dozen of speakers. The papers given during the seminar were preserved in NBS Special Publication 298, edited by Heinrich and issued during October 1968.

Automatic Data Acquisition

To assist scientists interested in the use of computers in the acquisition of laboratory data, Stanley D. Rasberry, Marvin Margoshes, and Bourdon F. Scribner described the use of a time-sharing computer in optical emission and x-ray fluorescence measurements.[228] Their installation involved the use of a teletype terminal that could utilize the Dartmouth College time-sharing computer system.

Chemical Constants

Robert A. Robinson and Roger G. Bates, in collaboration with A. K. Covington, a colleague on leave from the University of Newcastle-upon-Tyne in England, determined the ionization constant of deuterium oxide (heavy water) near room temperature.[229] The measurements were accomplished in an electromotive cell without a liquid junction; in presenting their results, the authors illustrated the differences among values of pK—the negative of the logarithm to the base 10 of the ionization constant—as expressed on the scales of molality (14.955), molarity (14.869) and mole fraction (16.653).

In August 1968 Marion Maclean Davis published Monograph 105, *Acid-Base Behavior in Aprotic Organic Solvents.* This 150-page work contained a unified picture of acid-base behavior in organic solvents of comparatively inert character. In such solvents as benzene, toluene, motor oils, and transformer oils, acids and bases behaved quite differently than they did in water; thus the solvents were often called "inert" or "aprotic." The study was based partly upon research done by the author and his colleagues, partly upon information obtained from literature in the field. Various erroneous ideas were corrected in the discussion, which contained a unifying explanation of acid-base concepts, hydrogen bonding, and types of acids, bases, and solvents.

Activation Analysis

Gilbert W. Smith, Donald A. Becker, George J. Lutz, Lloyd A. Currie, and James R. DeVoe illustrated the use of neutron activation analysis for the determination of the concentration of trace elements in high-purity substances such as Standard Reference

[227] K. F. J. Heinrich, "Electron probe microanalysis," in *Experimental Methods of Materials Research: Advances in Materials Research* (New York: John Wiley and Sons, Inc., 1967), pp. 145-162.

[228] S. D. Rasberry, M. Margoshes, and B. F. Scribner, "Applications of a time-sharing computer in a spectrochemistry laboratory: optical emission and x-ray fluorescence," *NBS Technical Note 407,* February 1968.

[229] A. K. Covington, R. A. Robinson, and R. G. Bates, "The ionization constant of deuterium oxide from 5 to 50 °," *J. Phys. Chem.* **70**, 3820-3824 (1966).

Materials.[230] The authors discussed the care necessary to obtain accurate results when using neutron activation analysis of trace impurities in complex materials; they found bias due to radiation unintentionally induced in the matrix, geometric placement errors, nonconstant shielding effects, and gamma-ray attenuation corrections.

In a related project, a four-person group from the division prepared a major compendium of references on activation analysis.[231] Dating the beginning of the activation analysis technique from work by Hevesy, Levi, Seaborg, and Livingood during the late 1930s, the Analytical Chemistry Division group noted that the rate of literature entries had grown exponentially over a 20-year period, exceeding 500 papers per year during 1968. George J. Lutz, Robert J. Boreni, Rosemary S. Maddock, and W. Wayne Meinke made up the group. They provided references to more than 8000 papers written throughout the world on activation analysis.

Crystal Studies

In a collaborative effort with Harvey Yakowitz of the Metallurgy Division, Donald L. Vieth developed a Kossel pattern generator to provide the means for obtaining crystal-lattice spacing with a precision of 1 ppm to 2 ppm and crystal orientation within an angle of 0.1°.[232] The instrument consisted of an electron beam column, a vacuum system, a light microscope, a film cassette, and a Kossel camera.

Polymers Division (Robert R. Stromberg, Acting Chief).

Work in the Polymers Division spanned the areas of dielectrics, under the leadership of Martin G. Broadhurst; the chemistry and physics of polymers, headed by Leo A. Wall and Ronald K. Eby, respectively; characterization, molecular and thermophysical properties, the first two areas in the charge of Cornelius A. J. Hoeve and the last under Alden B. Bestul; interfaces, led by Stromberg; and dental research, under George R. Dickson.

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[230] G. W. Smith, D. A. Becker, G. J. Lutz, L. A. Currie, and J. R. DeVoe, "Determination of trace elements in standard reference materials by neutron activation analysis," *Anal. Chim. Acta* **38**, 333-340 (1967).

[231] G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 1," *NBS Technical Note 467,* Part 1, September 1968;

G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 2—Appendices," *NBS Technical Note 467,* Part 2, September 1968;

G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 1, Addendum 1," *NBS Technical Note 467,* Part 1, Addendum 1, December 1969;

G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 2—Appendices, Revision 1," *NBS Technical Note 467,* Part 2, Revision 1, December 1969.

[232] D. L. Vieth and H. Yakowitz, "Design of a new Kossel pattern generator," *J. Res. NBS* **70C**, No. 4, 313-318 (1967).

Martin G. Broadhurst cut leaf wafers for a 1968 study of the dielectric properties of foliage. The data were employed in the design of radio antennas for use in heavily wooded areas.

Polymer Crystallization

John Lauritzen, Jr., an Institute Scientist, Elio Passaglia, newly appointed Chief of the Metallurgy Division, and Edmund A. DiMarzio discussed the kinetics of crystallization of binary mixtures of n-paraffins.[233] No data existed for this type of system, so the authors were constrained to a theoretical treatment of the topic. They employed a theory for the rate of growth of chains, assuming them to be strips of crystalline material composed of both components growing on a uniform substrate. They proposed a number of conclusions that would be subject to experimental verification.

Polymer Properties

With the collaboration of Jeffrey T. Fong, an NRC-NBS Postdoctoral Resident Research Associate, Jack C. Smith studied the mathematical theory of the coupling of longitudinal and transverse waves in a linear, three-element viscoelastic string that was subjected to transverse impact.[234]

[233] J. I. Lauritzen, Jr. , E. Passaglia, and E. A. DiMarzio, "Kinetics of crystallization in multicomponent systems: I. Binary mixtures of *n*-paraffins," *J. Res. NBS* **71A**, No. 4, 245-259 (1967).

[234] J. C. Smith and J. T. Fong, "On the coupling of longitudinal and transverse waves in a linear three-element viscoelastic string subjected to transverse impact," *J. Res. NBS* **72B**, No. 3, 201-214 (1968).

Theoretical models were developed for the dielectric and mechanical relaxation effects found in the polymers polyethylene and polychlorotrifluoroethylene. The new work, reported by John D. Hoffman, G. Williams, and Elio Passaglia, shed light on the processes of chain-folding in these polymers.[235]

Frederick I. Mopsik reported on the temperature, pressure and density variations of the dielectric constant of n-hexane.[236] He also described the apparatus used in the measurements, a cell that was both a bellows dilatometer and a three-terminal electrode set that could be used to measure the density and the dielectric properties of liquid samples *vs* temperature and pressure, from 120 K to over 300 K and from 100 kPa to 2×10^8 Pa, with an overall uncertainty of 0.03 %.

Shu-Sing Chang, J. A. Horman, and Alden B. Bestul studied the interesting thermal properties of diethyl phthalate both below and above its crystalline-glass transition.[237] The temperature range covered was 10 K to 360 K; the data appeared to be precise within about 0.1 %.

Gerhard M. Brauer, George Durany, and Harold Argentar measured the ionization constants of substituted benzoic acids in an ethanol-water solution, part of a study of the reactivity of substituted phenols.[238] They found that the pK values increased with ethanol content, but that the relative acid strength did not depend on solvent concentration.

Robert E. Lowry, Daniel W. Brown, and Leo A. Wall discussed the radiation-induced polymerization of hexafluoropropylene at high temperature and pressure.[239] The experimental temperature range was 100 °C to 230 °C and the pressure range was 4.5×10^8 Pa to 15×10^8 Pa. At the top of both ranges and under a radiation flux of 1.5 kilorad/h, the polymerization rate was 15 %/h.

Measurement Techniques

A new low-frequency bridge for the measurement of dielectric constants was described by W.P. Harris.[240]

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[235] J. D. Hoffman, G. Williams, and E. Passaglia, "Analysis of the α, β, and γ relaxations in polychlorotrifluoroethylene and polyethylene: dielectric and mechanical properties," *J. Polymer Sci. Pt. C,* No. 14, 173-235 (1966). This paper was listed by the Science Citation Index as a "Citation Classic" with more than 200 citations even during the period 1974-89, some 8-23 years after its publication.

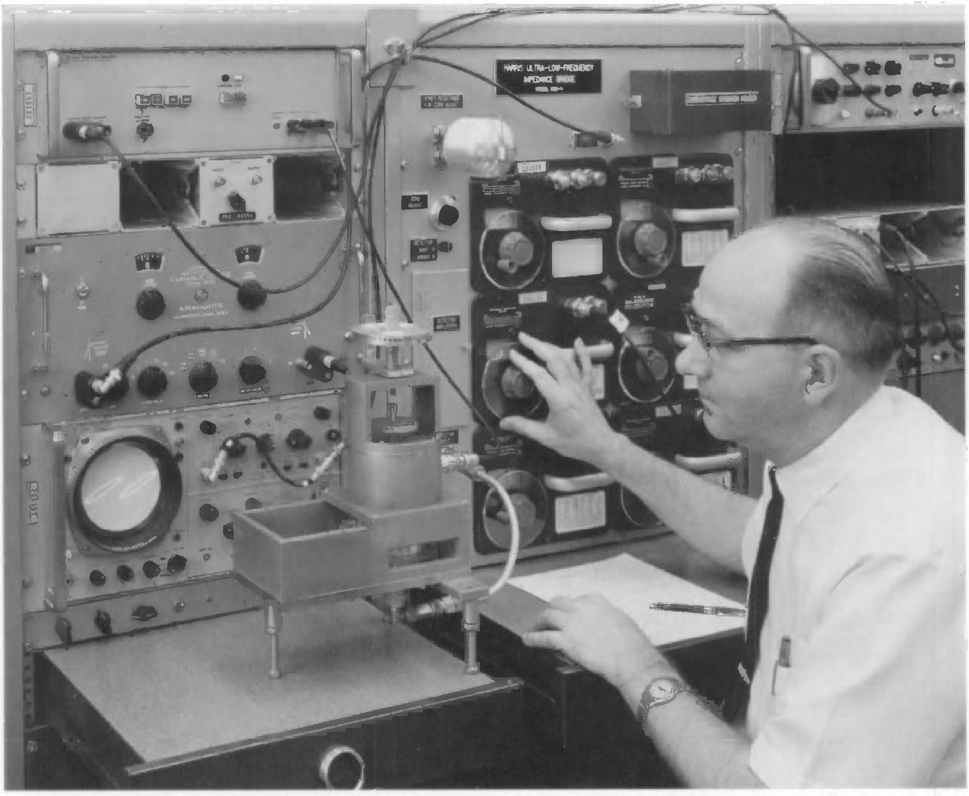
[236] F. I. Mopsik, "Dielectric constant of n-hexane as a function of temperature. pressure, and density," *J. Res. NBS* **71A**, No. 4, 287-292 (1967).

[237] S. S. Chang, J. A. Horman, and A. B. Bestul, "Heat capacities and related thermal data for diethyl phthalate crystal, glass, and liquid to 360 °K," *J. Res. NBS* **71A**, No. 4, 293-305 (1967).

[238] G. M. Brauer, G. Durany, and H. Argentar, "Ionization constants of substituted benzoic acids in ethanol-water," *J. Res. NBS* **71A**, No. 5, 379-384 (1967).

[239] R. E. Lowry, D. W. Brown, and L. A. Wall, "The radiation induced polymerization of hexafluoropropylene at high temperature and pressure," *J. Polymer Sci.* **4**, Part A-1, No. 9, 2229-2240 (1966).

[240] W. P. Harris, "A new ultra-low-frequency bridge for dielectric measurements," *1966 Annual Report Conf. Electrical Insulation and Dielectric Phenomena,* National Academy of Sciences-National Research Council, Mt. Pocono, PA, 1966, pp. 72-74.



William P. Harris of the National Bureau of Standards made dielectric measurements on a specimen with an NBS-constructed ultralow-frequency bridge. Such measurements were important for determining the suitability of materials for electrical insulation and for molecular behavior studies.

James P. Colson and Edward S. Clark, a colleague from duPont, produced tables of solutions to Bragg's equation for the Kα radiation from copper, cobalt, iron, and chromium.[241]

Dental Materials

A group of scientists working in the area of dental research, Philip L. Oglesby, George R. Dickson, M. L. Rodriguez, Ruth M. Davenport, and W. T. Sweeney, treated dental amalgams as viscoelastic materials.[242] They subjected the amalgams to tensile

[241] James P. Colson and Edward S. Clark, "Tables of solutions to Bragg's equation for copper, cobalt, iron, and chromium Kα radiation and small diffraction angles," *NBS Technical Note 461,* August 1968.

[242] P. L. Oglesby, G. Dickson, M. L. Rodriguez, R. M. Davenport, and W. T. Sweeney, "Viscoelastic behavior of dental amalgams," *J. Res. NBS* **72C**, No. 3, 203-213 (1968).

stress and successfully analyzed the results in terms of the theory of viscoelasticity. Dickson, Oglesby, and Davenport further analyzed dental amalgam in terms of its steady-state creep behavior.[243]

Metallurgy Division (Elio Passaglia, Chief).

Research in the Metallurgy Division covered many areas. A section on engineering metallurgy was in the charge of Melvin R. Meyerson. Lawrence H. Bennett headed the alloy physics section. Work on lattice defects and microstructure was led by Arthur W. Ruff. Metallic corrosion was studied in a section headed by Jerome Kruger. John R. Manning headed the metal physics section. Abner Brenner was chief of the electrolysis and metal deposition section, and Robert L. Parker headed the metal crystallization section.

Corrosion

Fielding Ogburn and M. Schlissel completed a corrosion study of galvanic pitting in metallic coatings.[244] In this project, they made use of an electrolytic cell which simulated a corrosion pit that extended through the metal coating. By the use of this technique they were able to measure the cell currents. Combinations studied included chromium, copper, and nickel on substrates of zinc, iron, nickel, and copper.

In a related study, Jerome Kruger and Joan P. Calvert, using a fast-recording ellipsometer, observed the kinetics of film growth on samples of iron that had been passivated in various ways.[245] Three stages of growth were differentiated: diffusion-limited, limitation by other processes, and logarithmic or inverse-logarithmic rates.

Crystal Growth

Sam R. Coriell, formerly a Postdoctoral Research Associate in the Heat Division, and Robert L. Parker reported a theoretical investigation of the interface kinetics and the stability of the shape of a solid sphere growing from the melt.[246]

With the assistance of Hans Oser of the Applied Mathematics Division, John A. Simmons and Sam Coriell developed an integral equation describing the rate of growth of "whiskers." [247]

[243] G. Dickson, P. Oglesby, and R. Davenport, "The steady-state creep behavior of dental amalgam," *J. Res. NBS* **72C**, No. 3, 215-218 (1968).

[244] F. Ogburn and M. Schlissel, "Galvanic pitting in metal coatings," *Plating* **54**, No. 1, 54-62 (1967).

[245] J. Kruger and J. P. Calvert, "Ellipsometric-potentiostatic studies of iron passivity. I. Anodic film growth in slightly basic solutions," *J. Electrochem. Soc.* **114**, No. 1, 43-49 (1967).

[246] S. R. Coriell and R. L. Parker, "Interface kinetics and the stability of the shape of a solid sphere growing from the melt," *Crystal Growth*, a Supplement to *J. Phys. Chem. Solids* **J3**, 703-708 (1967).

[247] J. A. Simmons, H. Oser, and S. R. Coriell, "On the solution of the Stefan problem for whisker growth," *Crystal Growth*, a Supplement to *J. Phys. Chem. Solids* **C8**, 255-264 (1967).

Field-Emission Microscopy

Allan J. Melmed was very productive during this period, even without considering work published jointly with other scientists. In 1967 he published a review of field-emission miscroscopy, treating the field-electron-emission microscope and the field-ion microscope separately. Elements covered included the imaging process and the capabilities, limitations and applications of each type of instrument.[248]

In the same year Melmed wrote a paper about diffusion on the surfaces of nickel and platinum leading to rearrangement which appeared to be due to a combination of electric fields and surface tension.[249] This process was studied by field-electron-emission spectroscopy. He also described the epitaxial growth of iron crystals by vapor deposition on tungsten field-emission point probes.[250] The crystals tended to nucleate in one particular crystallographic orientation.

In another study, Melmed observed differences between hexagonal-close-packed (hcp) and body-centered-cubic (bcc) metals in field-ion microscopy.[251] This work had been motivated in part by observations on field-ion micrographs of field-evaporated ruthenium compared with those of rhenium, both hcp.[252]

Melmed constructed a microscope that produced an electron shadow "image" of small electrically conducting objects in ultra-high vacuum. The instrument used an electron field emitter as a pseudo point source of electrons that shadowed the object on a phosphor screen.[253] In 1968 he wrote a chapter for a field-ion-microscopy text covering the topics of field-ion microscopy of whiskers, field-ion microscopy of thin films, field-ionization mass spectrometry, and biological-molecule imaging.[254]

Working with Howard P. Layer and Jerome Kruger, Melmed developed an experimental approach that permitted the simultaneous application of three techniques—ellipsometry, low-energy electron diffraction, and field-electron-emission microscopy—to the study of surface phenomena.[255] They demonstrated the technique by studying the adsorption of oxygen on the (001) plane of tungsten.

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[248] A. J. Melmed, "Field emission spectroscopy," chapter in *Advances in Materials Research*. Vol. **1**, Experimental Methods. H. Herman, editor, (New York: Interscience Publ. Inc., 1968), pp. 103-143.

[249] A. J. Melmed, "Surface self-diffusion of nickel and platinum," *J. Appl. Phys.* **38**, No. 4, 1885-1892 (1967).

[250] A. J. Melmed, "Epitaxial growth of iron on tungsten field emission points," *Surface Sci.* 7, No. 3, 478-81 (1967).

[251] A. J. Melmed, "Helium field-ion microscopy of hexagonal close-packed metals," *Surface Sci.* **8**, No. 12, 191-205 (1967).

[252] A. J. Melmed, "The structure of field-evaporated hexagonal close-packed metal surfaces: rhenium and ruthenium," *Surface Sci.* **5**, No. 3, 359-379 (1966).

[253] A. J. Melmed, "Field emission shadow spectroscopy," *Appl. Phys. Lett.* **12**, No. 3, 100-102 (1968).

[254] A. J. Melmed, "Whiskers, thin films, and applications (real and imagined) to mass spectrometry and biological molecule imaging," Chapter in *Field-Ion Microscopy*, J. J. Hren and S. Ranganathan, editors, (New York: Plenum Press Inc. , 1968), pp. 183-212.

[255] A. J. Melmed, H. P. Layer, and J. Kruger, "Ellipsometry, low energy electron diffraction and field emission microscopy combined," *Surface Sci.* **9**, 476-483 (1968).

Mechanical Properties

As part of a comprehensive program on the mechanical behavior of metals at elevated temperatures, William D. Jenkins and William A. Willard described creep tests on titanium-aluminum-molybdenum-vanadium alloys at temperatures as high as 650 °C.[256] Relation of the results to creep theory and to previous thermo-mechanical treatment of the materials yielded guidance for the engineering use of this type of material.

Mössbauer Effect

Lydon J. Swartzendruber reported the results of graduate research performed at the Bureau on the use of the Fe^{57} Mössbauer effect to study magnetic ordering in copper-rich copper-nickel-iron alloys.[257] Swartzendruber discussed the possible origin of a doublet structure observed in certain high-temperature spectra.

Properties of Nickel

A 150-page *NBS Monograph,* No. 106 issued in May 1968, illustrates one of the roles played by research associates at NBS. Samuel J. Rosenberg, a Research Associate from the International Nickel Company, prepared an extensive review of the available information on the production, properties, and uses of both high-purity and commercial forms of nickel and its alloys. Superseding a 10-year-old NBS Circular on the same topic, the document offered guidance on chemical and physical properties and methods of analysis.

Project Summaries

A summary of eight high-temperature, materials-research projects at NBS that were supported by the Advanced Research Projects Agency was edited by Elio Passaglia, the Metallurgy Division chief. [258] The projects were performed in several different divisions of NBS. Each project was briefly described by the scientist involved: diffusion in refractory metals, by John B. Wachtman, Jr. , and Alan L. Dragoo; deformation and fracture of ionic crystals, by Sheldon M. Wiederhorn and Leonard H. Bolz; optical constants of titanium, by Allan J. Melmed and James J. Carroll; high-temperature creep in metals, by Armin A. O. Rukwied, William A. Willard, and D. E. Darne; electronic structure of hard, refractory metals, by John R. Cuthill and

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[256] W. D. Jenkins and W. A. Willard, "Creep rupture properties of Ti-8Al-1Mo-1V alloy," *J. Res. NBS* **72C**, No. 2, 167-174 (1968).

[257] L. J. Swartzendruber, "Mössbauer effect study of magnetic ordering in copper-rich Cu-Ni-Fe alloys," NBS *Technical Note 463,* August 1968.

[258] "Research on high temperature materials at the National Bureau of Standards," Elio Passaglia, Editor, *NBS Technical Note 447,* July 1968.

Archie J. McAlister; crystal growth from vapor, by Harry S. Parker and Chester A. Harding; high-temperature crystal growth from solvents, by Jun Ito and Harold Johnson; high-temperature thermodynamics, by E. Dale West and Shigeru Ishihara; and the volatilization and decomposition of materials, by Joseph H. Flynn, Sidney Strauss, Lee A. Dunlap, and Leo A. Wall.

Inorganic Materials Division (John B. Wachtman, Jr.).

The Inorganic Materials Division consisted of six sections: inorganic chemistry, with Thomas D. Coyle at the helm; inorganic glass, under Wolfgang K. Haller; high-temperature chemistry, William S. Horton, chief; inorganic physical properties, under Sheldon M. Wiederhorn; crystallography, led by Stanley Block; and solid-state physics, Hans P.R. Frederikse, chief.

Calibrations

The Inorganic Materials Division provided calibration service for several magnetic materials used as standards. NBS Special Publication 250 listed tests for normal induction and hysteresis, and ac permeability and core loss. The Division's Solid State Physics Section, which performed these calibrations, also calibrated magnetic testing apparatus, including mutual inductors, search coils, fluxmeters, solenoids, Helmholtz coils, and standard magnets.

Crystal Studies

As part of a continuing study of the motion of point defects in crystals, H. Steffen Peiser and John B. Wachtman, Jr., reported further conclusions regarding symmetry conditions that influence such motion.[259] The authors concluded that the symmetry groups describing the trap and the defect strongly influence or completely determine the rate of migration, or "jump."

The subject of mass transport in oxides was the topic of a symposium held at NBS late in 1967. The proceedings of the symposium, edited by John B. Wachtman, Jr., and Alan D. Franklin, were published in *NBS Special Publication 296,* issued in August 1968. About 100 scientists and engineers from the United States, Great Britain, the Netherlands, Canada, Australia, and France attended the four-day meeting. Specialized topics addressed by the speakers included the motion of point defects and impurity ions, lattice dynamics, diffusion coefficients, and ionic conductivity.

Melting Phenomena

Samuel J. Schneider, Jr. and Clyde L. McDaniel studied the effects of various atmospheres on the melting temperature of Al_2O_3.[260] The authors noted the effects of

[259] H. S. Peiser and J. B. Wachtman, Jr., "Jump rates for point defects in special positions held by a trapping center of noncubic symmetry," *J. Res. NBS* **72A**, No. 3, 231-237 (1968).

[260] S. J. Schneider and C. L. McDaniel, "Effect of environment upon the melting point of Al_2O_3," *J. Res. NBS* **71A**, No. 4, 317-333 (1967).

vacuum, air, argon, and helium, with the samples contained in iridium or tungsten holders. The samples appeared to be least disturbed when contained in a vacuum environment. Induction heating was used to melt the specimens. The melting temperature of Al_2O_3 *in vacuo* was determined as (2051 ± 6) °C on the *International Temperature Scale.* The experimental imprecision level was ±1.5 °C.

Surface Effects

Alan D. Franklin, Samuel Marzullo, and John B. Wachtman, Jr., studying the dielectric spectrum of CaF_2, observed the effects of surface-layer relaxation.[261] The surface-layer conductivity of samples doped with 0.1 % GdF_3 appeared much higher than the bulk values; the authors attributed this effect to large numbers of anion vacancies produced by dissolved oxygen.

Spin-Lattice Relaxation

The process of energy exchange between the paramagnetic spin system of neodymium ethylsulfate and its matrix was studied by use of electron spin resonance (ESR) techniques by George A. Candela and Robert E. Mundy.[262] This salt was particularly interesting because it was used in low-temperature paramagnetism studies following an early demonstration of its utility by Horst Meyer.[263] The dominant lattice-bath relaxation time was found to be inversely proportional to the square of the bath temperature, but independent of the crystal size or orientation.

Optical Properties of $SrTiO_3$

Robert F. Blunt and Martin I. Cohen reported on the creation of color centers in MgF_2 by the use of 50 kV x rays.[264] They tentatively identified F centers as the source of an absorption band near 260 nm. Blunt and Cohen also determined the absorption coefficient, the reflectivity and the electroreflectance near the fundamental absorption edge in $SrTiO_3$, a material which was interesting both as a semiconductor and as a superconductor.[265]

[261] A. D. Franklin, S. Marzullo, and J. B. Wachtman, Jr., "Surface-layer relaxation in the dielectric spectrum of CaF_2 doped with GdF_3," *J. Res. NBS* **71A**, No. 5, 355-362 (1967).

[262] G. A. Candela and R. E. Mundy, "Influence of paramagnetic resonance on the static susceptibility. The lattice-bath relaxation time of neodymium ethylsulfate," *J. Chem. Phys.* **46**, No. 1, 47-54 (1967).

[263] H. Meyer, *Phil. Mag. 2*, 521 (1957).

[264] R. F. Blunt and M. I. Cohen, "Irradiation-induced color centers in magnesium fluoride," *Phys. Rev.* **153**, 1031-1038 (1968).

[265] M. I. Cohen and R. F. Blunt, "Optical properties of $SrTiO_3$ in the region of the absorption edge," *Phys. Rev.* **168**, No. 3, 929-933 (1968).

A theoretical study of the optical properties of $SrTiO_3$ under mechanical stress and electric fields was reported by Russell C. Casella.[266] $SrTiO_3$, the only known oxide superconductor, had been the subject of experiments on the relation between superconducting transition temperature and uniaxial stress. Casella's calculations indicated that the position of the Fermi surface was very susceptible to uniaxial stress; experimental observation of the large influence of uniaxial stress on the superconducting transition temperature corroborated his ideas. Ludwig H. Grabner described experiments on photoconductivity and luminescence in the same material during a conference on the physics of the solid state.[267]

X-Ray Powder Patterns

Standard x-ray diffraction powder patterns for some 140 substances were presented by Howard E. Swanson, Howard F. McMurdie, Marlene C. Morris, and Eloise H. Evans. Miller indices for d-values, densities, and refractive indices were included wherever possible. Publication of the patterns took place as Sections 6 and 7 of NBS Monograph 25, a comprehensive document that, beginning in 1962, superseded NBS Circular 539 as a source of up-to-date information useful in identifying many materials.

Ceramics

Wachtman also served as editor for the 250-page proceedings of a symposium on Mechanical and Thermal Properties of Ceramics, sponsored by the American Ceramic Society, the American Society for Testing and Materials, and NBS.[268] The symposium was held at the Gaithersburg site on April 1-2, 1968. Fourteen papers, half of them by Bureau scientists, were presented before some 210 participants of the symposium.

Physical Chemistry Division (James R. McNesby).

The activities of the Physical Chemistry Division took place in six sections. The leaders of these sections were George T. Armstrong, thermochemistry; Ralph Klein, surface chemistry; David Garvin, elementary processes; Henry M. Rosenstock, mass spectrometry; McNesby, photochemistry; and Pierre J. Ausloos, radiation chemistry.

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[266] R. C. Casella, "Optical properties of $SrTiO_3$ under applied stress and electric field," *Phys. Rev.* **154**, No. 3, 743-749 (1967).

[267] L. H. Grabner, "Oscillatory photoconductivity and luminescence in $SrTiO_3$," *Proc. Cairo Solid State Conf. American University, Cairo, Egypt, Sept. 3-8, 1966,* (Book, Interaction of Radiation With Solids, A. Bishay, editor, (New York: Plenum Press Inc. , 1967), pp. 155-160.

[268] J. B. Wachtman, Jr., editor, "Mechanical and thermal properties of ceramics," *Proceedings of a Symposium Held at Gaithersburg, MD, April 1-2, 1968, NBS Special Publication 303,* May 1969, 275 pages.

Thermodynamic Data

A 260-page revision of Tables 23, 33, and 34 of Series I of NBS Circular 500, *Selected Values of Chemical Thermodynamic Properties,* was published in 1968 by Donald D. Wagman, William H. Evans, Vivian B. Parker, Iva Halow, Sylvia M. Bailey, and Richard H. Schumm.[269] In the course of revising the massive circular, eight NBS Technical Notes (270-1 through 270-8) were published over a period of time. In 1982 these were compiled into a single document by the scientists named above with the collaboration of Kenneth L. Churney and Ralph L. Nuttall.[270]

Calorimetry

Eugene S. Domalski and George T. Armstrong completed several calorimetric projects during the period 1967-68. Much of this work was accomplished while they participated in a Heat Division program—a U.S. Air Force project on the use of refractory materials for rocket propellants. Using a bomb calorimeter, the authors determined the heat of formation of crystalline boron in gaseous fluorine.[271] They also provided measurements of the heats of formation of two aluminum borides, AlB_2 and AlB_{12}.[272] And they were able to deduce the heat of formation of a boron carbide of composition $B_{4.222}C$ by measuring the heats of combustion of polytetrafluoroethylene and of boron carbide-polytetrafluoroethylene mixtures.[273]

Photolysis and Radiolysis

An interesting series of papers on the topics of photolysis and radiolysis was written during this period by Pierre J. Ausloos in collaboration with several colleagues. With Sharon G. Lias, he investigated isobutane in the gas phase, obtaining information on the possible modes of decomposition;[274] with Lias and Richard E. Rebbert, he discussed the structure of propyl ions formed in the radiolysis of alkanes;[275] the same

[269] D. D. Wagman, W. H. Evans, V. B Parker, I. Halow, S. M. Bailey, and R. H. Schumm, "Selected values of chemical thermodynamic properties. Tables for the first thirty-four elements in the standard order of arrangement," *NBS Technical Note 270-3,* January 1968, 267 pages.

[270] D. D. Wagman, W. H. Evans, V. B. Parker, R. H. Schumm, I. Halow, S. M. Bailey, K. L. Churney, and R. L. Nuttall, "The NBS tables of chemical thermodynamic properties. Selected values of inorganic and C_1 and C_2 organic substances in SI units," *J. Phys. Chem. Ref. Data* **11**, Supplement No. 2, 392 pp. (1982).

[271] E. S. Domalski and G. T. Armstrong, "The heat of formation of boron trifluoride by direct combination of the elements," *J. Res. NBS* **71A**, No. 3, 195-202 (1967).

[272] E. S. Domalski and G. T. Armstrong, "Heats of formation of aluminum diboride and α-aluminum dodecaboride," *J. Res. NBS* **71A**, No. 4, 307-315 (1967).

[273] E. S. Domalski and G. T. Armstrong, "The heat of formation of boron carbide," *J. Res. NBS* **72A**, No. 2, 133-139 (1968).

[274] S. G. Lias and P. Ausloos, "Gas-phase photolysis and radiolysis of isobutane," *J. Chem. Phys.* **48**, No. 1, 392-400 (1968).

[275] P. Ausloos, R. E. Rebbert, and S. G. Lias, "Structure and reactivity of propyl ions in gas-phase radiolysis," *J. Am. Chem. Soc.* **90**, No. 18, 5031-5033 (1968).

authors reported results of the photolysis of cyclohexane, observing the production of ions and superexcited molecules.[276] Rebbert and Ausloos also performed photolysis at low temperatures, observing the production of free radicals from methyl iodide in various organic matrices.[277]

Vernon H. Dibeler, James A. Walker, and Susan K. Liston completed the latest work in a comprehensive mass spectrometric study of photoionization, obtaining photoionization efficiency curves for molecular NO_2, NO, and for fragments of these molecules.[278]

Walter Braun, Karl H. Welge, and James R. McNesby reported flash photolysis results on methane, performed in the vacuum ultraviolet range.[279] This was to be the first of a series of articles on this topic.

Using photolysis to produce atomic fluorine at 14 K, Marilyn E. Jacox and Dolphus E. Milligan detected the presence of the free radicals $H(^{14}N)F$, $H(^{15}N)F$, and $D(^{14}N)F$ resulting from the reaction of the fluorine with NH in an argon matrix.[280] This was the first observation of the species HNF. Using infrared and visible-ultraviolet spectroscopy, Jacox and Milligan were able to identify vibrational fundamental lines and electronic transitions involving molecular bending modes.

Theory of Chemical Reactions

A calculation of the energy surfaces for interaction of two atomic states of the element lithium with hydrogen molecules was reported by Morris Krauss.[281] Krauss also prepared a 139-page compendium illustrating the successes and failures of variational ab initio calculations of molecular properties, especially electronic energies, as found in the scientific literature.[282]

Frederick H. Mies and Morris Krauss reported the development of a quantum-mechanical theory describing the behavior of reacting molecular species and the effect on the reaction rate constant.[283]

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[276] P. Ausloos, R. E. Rebbert, and S. G. Lias, "Gas-phase photolysis of cyclohexane in the photoionization region," *J. Phys. Chem.* **72**, No. 11, 3904-3914 (1968).

[277] R. E. Rebbert and P. Ausloos, "Photolysis of methyl iodide in matrices of organic compounds at 20 ° and 77 °K. Reactions of hot methyl radicals," *J. Chem. Phys.* **48**, No. 1, 306-311 (1968).

[278] V. H. Dibeler, J. A. Walker, and S. K. Liston, "Mass spectrometric study of photoionization. VII. Nitrogen dioxide and nitrous oxide," *J. Res. NBS* **71A**, No. 5, 371-378 (1967).

[279] W. Braun, K. H. Welge, and J. R. McNesby, "Flash photolysis of methane in the vacuum ultraviolet. I. End-product analysis," *J. Chem. Phys.* **45**, No. 7, 2650-2656 (1967).

[280] M. E. Jacox and D. E. Milligan, "Production and reaction of atomic fluorine in solids. Vibrational and electronic spectra of the free radical HNF," *J. Chem. Phys.* **46**, No. 1, 184-191 (1967).

[281] M. Krauss, "Interaction energy surfaces for $Li(2^2S)$ and $Li(2^{2P})$ with H_2," *J. Res. NBS* **72A**, No. 6, 553-557 (1968).

[282] Morris Krauss, "Compendium of ab initio calculations of molecular energies and properties," *NBS Technical Note 438*, December 1967.

[283] F. H. Mies and M. Krauss, "Time-dependent behavior of activated molecules. High-pressure unimolecular rate constant and mass spectra," *J. Chem. Phys.* **45**, No. 12, 4455-4468 (1966).

Surface Studies

Adsorption of nitrogen on rhenium metal was studied with the use of the field-ion microscope, which permits atom-by-atom examination of samples, by Ralph Klein and James W. Little.[284] Klein and Little undertook the study in order to extend the field-ion adsorption method from body-centered and face-centered cubic metals to the hexagonal-close-packed structure.

The two scientists were successful in obtaining clear field-ion patterns from the nitrogen-covered rhenium surface, which closely mimicked those of a clean rheniun surface. Their results allowed them to discuss the modes and locations of the adsorption process, as well as some of the energetics involved.

Institute for Applied Technology (Lawrence M. Kushner, an expert in metal physics, was newly appointed as director of IAT in 1968).

The IAT provided a wide range of technical services to promote the use of available technology and to facilitate innovation in technology in industry and government.

Manager, Engineering Standards (Malcolm W. Jensen, Manager).

Jensen's duty was to plan and administer the programs of the Office of Weights and Measures and the Office of Engineering Standards Services and to help formulate policy with respect to engineering standards. Rudolph A. Vignone, an attorney, helped to avoid legal problems in this area.

Office of Engineering Standards Services (Donald R. Mackay, Chief).

The OESS assisted government at all levels, as well as industry, in developing product and safety standards. Sampling, testing, and dissemination of information on standards were part of the workload of this office. Herbert A. Philo directed the work in product standards. William J. Slattery was acting chief of the standards information section. Mackay filled the role of chief of mandatory standards.

In collaboration with Malcolm Jensen and a committee of the U.S. National Conference on Weights and Measures, Mackay prepared in 1965 the third edition of NBS Handbook 44 *Specifications, tolerances, and other technical requirements for commercial weighing and measuring devices.* This handbook, first issued in 1949, provided assistance to individual states in their efforts to achieve uniformity of weights and measures laws and methods of inspection. It incorporated sections on scales, weights, liquid measure, linear measure, fabrics, cordage, taximeters, odometers, dry measures, and tables of equivalents.

[284] Ralph Klein and James W. Little, "Nitrogen on rhenium observed with the field emission microscope," *Surface Sci.* **6**, No. 2, 193-207 (1967).

Office of Weights and Measures (Malcolm W. Jensen, Chief).

The OWM provided assistance to the states and to industry in the area of model laws and regulations and all the many features of maintaining the usefulness of standards of weights and measures. This assistance included training of weights and measures officials as well as consultation on legal requirements.

In June 1968 the 53rd National Conference on Weights and Measures was held at a large Washington, DC, hotel. The week-long conference was an important tool in the effort of NBS and weights and measures officials from all levels of government, industry, and consumer organizations for coordinating their activities. Daily sessions permitted the airing of many issues relating to weights and measures. Allen Astin, Director of NBS, served as the Conference President, and Malcolm Jensen, OWM chief, was the Conference Secretary. Standing committees existed on liaison with the Federal government, on education, on specifications and tolerances, and on laws and regulations.

Office of Invention and Innovation (Daniel V. De Simone, Chief).

This office had the responsibility for analyzing the effect of Federal laws on invention and innovation throughout the United States. In addition, the office encouraged invention through specific programs and by collaboration with state governments. These activities were carried out in three program areas: the innovation studies program, Joseph D. Crumlish, chief; the invention programs, Leonard S. Hardland, chief; and the engineering education program, John M. Tascher, chief.

De Simone described some of the principles of educating students in the concepts of innovation in an article published by the journal *IEEE Spectrum*.[285] The discussion advocated an engineering curriculum, with emphasis on fostering creativity.

Office of Vehicle Systems Research (Paul J. Brown, Chief).

This office was the focus of a collaborative effort between NBS and the National Highway Safety Bureau to provide the technical basis for Federal safety standards for motor vehicles and other motorized equipment. Its staff also had responsibility for developing methods to determine the levels of compliance with these standards.

Most of the work of the office was accomplished in three sections: tire systems under F. Cecil Brenner, occupant-restraint systems led by Richard W. Armstrong, and braking systems with Robert J. Forthofer as chief.

Clearinghouse for Federal Scientific and Technical Information (Hubert E. Sauter, Director).

The Clearinghouse provided a single point of contact within the Federal government through which the general public could obtain the results of government-sponsored research. Translation service also was available through this office.

[285] D. V. De Simone, "Education for Innovation," *IEEE Spectrum* 5, No. 1, 83-90 (1968).

As part of a 1968 research project, Glenn Ludwig of the NBS Office of Vehicle Systems Research (OVSR) adjusted an antenna for picking up a telemetry signal indicating tire temperature. The instrumentation was used to study tire performance under an automobile safety program conducted by OVSR for the Department of Transportation's National Highway Safety Bureau.

Enormous numbers of publications were involved in the work of the Clearinghouse; a substantial organization was required to fulfill its work. The organization consisted of four branches in addition to a joint publications research service headed by Gustav Blackett. The branches were:

- Document distribution and reproduction, Alvin W. Alexander, chief.
- Automated systems and services, M. A. Krazny, chief.
- Administrative operations, Joseph G. Coyne, chief.
- Document processing, George K. Kudravetz, acting chief.

Product Evaluation Division (Sanford B. Newman, Chief).

This division developed measurement techniques and test methods for technical materials; maintained standard reference materials for rubber and paper; advised other government agencies on product standards; and performed developmental work on materials of interest to Federal agencies.

Five sections existed in the division: plastics and textiles, Karl F. Plitt, chief; fibrous systems, Donald G. Fletcher, chief; viscoelastic materials, George E. Decker, acting chief; paper evaluation, William K. Wilson, chief; and fabric flammability, James V. Ryan, chief.

Among other responsibilities, this division was home to the work mandated by the *Flammable Fabrics Act.*

NBS/GSA Test and Development Division (Phillip J. Franklin, Chief).

To assist the General Services Administration in evaluating the myriad products purchased each year for the Federal government, the Bureau maintained a small division with the responsibility for testing certain of these products. Among the items routinely tested by the NBS/GSA Test and Development Division were batteries, lamps, security cabinets, chemicals, and concrete. The division also had the capability to perform mechanical testing and soil testing.

The activities of this division were considered more relevant to GSA than to the Bureau. Just before his retirement, Allen Astin arranged the transfer of the division to GSA.

Building Research Division (James R. Wright, Chief).

Under the leadership of John P. Eberhard—trained as an architect and Director of the Institute for Applied Technology in 1966-67—and BRD chief James R. Wright, the Bureau's building research program underwent a complete reorientation with the move to the Gaithersburg site. The more spacious facilities permitted the group to study the behavior of entire buildings rather than to limit its research efforts to building components and materials. In addition, emphasis was placed on assisting governmental analysis of building problems and on participating in the new National Conference of States on Building Codes.

As a result of the broadened scope, the Bureau's building research program was given a new focus: fleshing out the concept of performance standards. In an article for *Scientific American,* Wright explained the idea:

> The performance approach demands a statement of performance in terms of function. Since buildings serve people, function is defined by the attributes necessary to serve human requirements. The means of delivering an attribute is open. It is in this way that the builder or supplier of a building component is invited to innovate. Indeed, the encouragement of innovation is sometimes cited as the reason for the performance approach. In any event, the philosophy of performance begins and ends with—and puts its principal emphasis on—the satisfaction of human needs.[286]

[286] James R. Wright, "Performance criteria in building," *Scientific American,* March 1971, pp. 16-25.

As part of its responsibility for developing criteria for performance standards for building products, structures, and systems, the BRD collaborated with the building industry, with other government agencies, and with professional associations. A major project, *Operation Breakthrough,* was shared with the Department of Housing and Urban Development (see Sect. 2.8.15).

Besides its other responsibilities, this division responded to the demands of the *Fire Research and Safety Act.*

The sections of the division and their chiefs were the following:

- Structures, Edward O. Pfrang.
- Fire research, Irwin A. Benjamin.
- Environmental engineering, Henry E. Robinson.
- Materials durability and analysis, William C. Cullen.
- Codes and standards, Gene A. Rowland.
- Building systems, R. W. Blake.
- Scientific and professional liaison, W. W. Walton.

Thermal Measurements

Paul R. Achenbach, Clinton W. Phillips, and Ronald W. Penney offered a testing and rating method for the cooling loads of refrigerated trucks.[287] This work was sponsored by the U.S. Department of Agriculture to assist the haulers of frozen foods or fresh produce. Achenbach also described new NBS test procedures for evaluating the performance criteria for building components and systems, including heating, air conditioning, and sanitary plumbing.[288]

Materials Properties

Charles M. Hunt reported to the *Highway Research Board Symposium* the results of nitrogen sorption measurements and surface areas of hardened cement pastes.[289]

In an effort to create a basis for the use of commercial platinum as a thermal conductivity reference material, Daniel R. Flynn and M. E. O'Hagan, a doctoral candidate at the George Washington University, studied both its thermal conductivity and electrical resistivity in the range 100 °C to 900 °C.[290]

[287] P. R. Achenbach, C. W. Phillips, and R. W. Penney, "A testing and rating method for refrigerated trucks with respect to cooling load," *Annex to Proc. Intern. Inst. Refrigeration, Comm. VII,* (London, England, Sept. 1966), pp. 29-35.

[288] P. R. Achenbach, "Performance criteria for building components and systems," *Proc. Porcelain Enamel Institute Forum, University of Illinois, Urbana, Ill., Sept. 28-30, 1966,* **28**, 176-195 (1966).

[289] C. M. Hunt, "Nitrogen sorption measurements and surface areas of hardened cement pastes," (Highway Research Board Symp. Structure of Portland Cement Paste, Washington, DC, January 1965). *Highway Research Board Special Report* **90**, 112-122 (1966).

[290] D. R. Flynn and M. E. O'Hagan, "Measurements of the thermal conductivity and electrical resistivity of platinum from 100 to 900 °C," *J. Res. NBS* **71C**, No. 4, 255-284 (1967).

Along with his colleague Bradley A. Peavy, Jr., Flynn served as co-editor of the 800-page proceedings of the Seventh Conference on Thermal Conductivity, held November 13-16, 1967 at the Gaithersburg site.[291] This conference series was initiated in 1961 by participants in the *Symposium on Temperature, Its Measurement and Control in Science and Industry,* who wished to provide an extended forum for the discussion of high-temperature thermal conductivity measurements in solids. The eighth *Thermal Conductivity Conference* included more than 180 participants from 11 countries. The 90 papers presented by these scientists appeared in sessions on theory, methods, metals at low and high temperatures, non-metallics, nuclear materials, construction materials, gases, liquids, two-phase systems, and conductivity across interfaces. The proceedings of previous thermal conductivity conferences had not been published, thus preventing much of the material from reaching the open literature. A ninth conference was held at Iowa State University during October 1969.

Sub-freezing measurements of important properties—breaking load, elongation and thermal expansion—for nine types of built-up roofs were outlined by Thomas H. Boone, Leopold F. Skoda, and William C. Cullen.[292] One purpose of the study was to elucidate the differences between roofing membranes prepared in the field by roofing contractors and those prepared in the laboratory by NBS laboratory technicians. The performance of the field-prepared roofing was found to be substantially the same as the laboratory samples, justifying the retention of existing standards of construction.

Fire Studies

A study of the effectiveness of dwelling-unit entrance doors as barriers to fire and smoke was described in the Building Science Series by Harry Shoub and Daniel Gross.[293] Without raising their fire resistance or their smoke resistance to the level of commercial doors, an impractical goal, various suggestions were offered to improve the performance of the doors. For example, they found that smoke penetration into apartments from a smoke-filled corridor could be minimized by providing suitable openings in an exterior wall of the corridor; if the openings were above the top of the door, air would tend to flow from the room to the corridor and thence out of the openings.

Instrumentation

E. Carroll Creitz refined the ideas underlying the use of the Nerheim version of the Martin gas-density balance as a detector in gas chromotography.[294] Creitz showed how to better define the significant balance variables for column effluents of differing densities.

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[291] Daniel R. Flynn and Bradley A. Peavy, Jr. , Editors, "Thermal Conductivity; Proceedings of the Seventh Conference," *NBS Special Publication 302,* September 1968.

[292] T. H. Boone, L. F. Skoda, and W. C. Cullen, "Laboratory-field comparisons of built-up roofing membranes," *NBS Technical Note 473,* December 1968.

[293] H. Shoub and D. Gross, "Doors as Barriers to Fire and Smoke," *Building Science Series* 3, March 1966, 10 pp.

[294] E. C. Creitz, "Gas density balance design considerations," *J. Res. NBS* **72C**, No. 3, 187-195 (1968).

Electronic Technology Division (Myron G. Domsitz, Chief).

The ETD had responsibility for developing criteria for the evaluation of electronic instrumentation—including standards and codes—and for identifying needs for new technological instrumentation. Four sections accomplished these tasks: semiconductor characterization, under W. Murray Bullis; electron devices, Judson C. French, chief; instrumentation application, led by Joshua Stern; and semiconductor processing, under Joseph A. Coleman.

Data Compilations

A compilation of data on Soviet electronic devices was prepared by Charles P. Marsden.[295] The compilation was prepared as part of the Bureau *Electron Devices Data Service,* established in 1948 for NBS staff guidance on nearly two dozen types of vacuum tubes, transistors, and other devices.

Semiconductor Measurements

A progress report on methods of measurement used in the areas of semiconductor materials, process control, and electronic devices, assembled by W. Murray Bullis, provided the reader with a wealth of information on this Bureau activity.[296] The project was sponsored jointly by NBS, the Defense Atomic Support Agency, the U.S. Naval Ammunition Depot, and the National Aeronautics and Space Administration. Some 40 NBS staff members involved in the project were identified, related activities were briefly noted, and some 15 types of semiconductor measurements were outlined.

Harry A. Schafft and a colleague, Susan Gayle Needham, prepared a bibliography on the methods for measuring inhomogeneities in semiconductors.[297] The types of inhomogeneities discussed related to resistivity, impurity concentration, diffusion length, lifetime, surface conditions, mobility, and p-n junctions.

A more specialized survey—on minority carrier lifetimes—was prepared by W. Murray Bullis.[298] Containing references to about 300 papers, the survey covered measurement methods, typical results, and theoretical models.

[295] C. P. Marsden, "Tabluation of published data on Soviet electron devices through October 1967," *NBS Technical Note 441,* July 1968.

[296] "Methods of measurement for semiconductor materials, process control, and devices. Quarterly report July 1 to September 30, 1968," W. Murray Bullis, Editor, *NBS Technical Note 472,* December 1968.

[297] H. A. Schafft and S. G. Needham, "A bibliography on methods for the measurement of inhomogeneities in semiconductors (1953-1967)," *NBS Technical Note 445,* May 1968.

[298] W. M. Bullis, "Measurement of carrier lifetime in semiconductors—an annotated bibliography covering the period 1949-1967," *NBS Technical Note 465,* November 1968.

The phenomenon of high-current transistor operation known as "second breakdown," an increasingly prevalent problem, was discussed in detail by Harry A. Schafft and Judson C. French in order to document the status of public understanding of the phenomenon.[299]

Another contribution to the understanding of transistor electronics came from Joseph A. Coleman and Lydon J. Swartzendruber, who provided an analysis of the effective charge-carrier lifetime in positive-intrinsic-negative (p-i-n) junctions in silicon.[300]

Measurement Methods

Paul S. Lederer discussed the *Interagency Transducer Project,* work done at the Bureau since 1951 and supported in 1968 by the National Aeronautics and Space Administration and by the U.S. Department of Defense.[301] The project was important to the supporting agencies because of the critical dependence of many telemetry techniques on the quality and performance of the transducer involved. The NBS participants provided performance data and developed standardized test procedures for a variety of sensors, including accelerometers, shock tubes, vibration sensors, and pressure sensors. Lederer also provided details of the performance testing of electromechanical pressure transducers, used in aerospace testing and a variety of other applications.

Technical Analysis Division (Walter E. Cushen, Chief).

In this division, cost-benefit analyses on other Institute programs were conducted. It was hoped that this approach to management systems would be useful throughout the government. Managers of the different program areas were: socio-economic studies, George Suzuki, acting chief; simulation and transportation studies, Louis C. Santone; operations research in behavioral sciences, June Cornog; Post Office studies, William F. Druckenbrod; and corridor model systems, Ralph E. Schofer.

Center for Computer Sciences and Technology (Herbert R.J. Grosch, Director).

This center had responsibility for research and technical support for the General Services Administration under provisions of *Public Law 89-306,* the "Brooks Act" which required NBS to provide guidance to the U.S. government on automatic data processing (ADP).

[299] H. A. Schafft and J. C. French, "A survey of second breakdown," *IEEE Trans. Electron. Devices* **ED-13**, No. 8-9, 613-618 (1966). More information on this topic appears in Ch. 6.

[300] J. A. Coleman and L. J. Swartzendruber, "Effective charge carrier lifetime in silicon p-i-n junction detectors," (Proc. 10th Scintillation and Semiconductor Counter Symp., Washington, DC, March 23-24, 1966), *IEEE Trans. Nucl. Sci.* **NS-13**, No. 3, 240-244 (1966).

[301] P. S. Lederer, "Performance testing, pressure transducers," *Instr. Control System* **40**, No. 9, pp 93-99, Sept. 1967. See also P. S. Lederer, "Life Cycling' test on several strain gage pressure transducers," *NBS Technical Note 434,* October 1967 and P. S. Lederer, "NBS interagency transducer project," *NBS Technical Note 469,* October 1968.

The Bureau developed a number of techniques and devices for calibrating and evaluating transducers within the Interagency Transducer Project. In this photograph, NBS engineer Paul Lederer prepared to trigger a pneumatic step-function calibrator.

As Director, Grosch established policy on ADP and directed the work of two offices and three divisions:

Office for Information Processing Standards (Joseph O. Harrison, Jr., Chief)

This office coordinated programs and standards on computer-generated information processing throughout the government.

Office for Technical Information Exchange (Margaret R. Fox, Chief)

The Technical Information Exchange office provided a referral service for programs on automatic data processing.

Computer Services Division (W.B. Ramsay, Acting Chief)

The CSD staff provided computing and data-conversion services to NBS and other agencies.

Systems Research and Development Division (Charles T. Meadow, Chief)

The SRDD evaluated existing computer systems.

Chemical Structures on Computers

A useful project undertaken in this division provided guidance in the transposition of chemical structures for use with computers. George F. Fraction, Justin C. Walker, and Stephen J. Tauber wrote a brief account of this type of work in an NBS Technical Note.[302]

Assembly Language

Input-output software for use with the Assembly Language Processor of the Systems 360 computer was described by Paul A. D. deMaine.[303]

Character Recognition

Mary Elizabeth Stevens reported on European progress in the recognition by computer of optical characters and other patterns, library automation, and linguistic data processing.[304]

Computer Graphing

A study of the theory of specialized graphs was completed by Arthur M. Hobbs and Jerrold W. Grossman.[305]

Electronic Printing

In February 1968, NBS issued *Special Publication 295,* edited by Richard W. Lee and Roy W. Worral. It contained the proceedings of a symposium on electronic composition in printing that had been held at the Bureau the previous summer. The four sessions of the symposium covered the following topics: State of the Art, Government

[302] G. F. Fraction, J. C. Walker, and S. J. Tauber, "Connection tables from Wiswesser chemical structure notations—a partial algorithm," *NBS Technical Note 432,* September 1968.

[303] P. A. D. deMaine, "Input/output packages for the Systems 360 assembly language processor," *NBS Technical Note 433,* September 1968.

[304] M. E. Stevens, "Nonnumeric data processing in Europe: a field trip report," *NBS Technical Note 462,* November 1968.

[305] A. M. Hobbs and J. W. Grossman, "A class of thickness-minimal graphs," *J. Res, NBS* **72B**, No. 2, 145-153 (1968).

Policy, Non-Government Applications and Research, and Government Applications. The Government Printing Office and the congressional Joint Committee on Printing figured strongly in the setting of policy on electronic composition.[306]

Information Processing Technology Division (James P. Nigro, Chief)

This division utilized computer methods for information processing.

Fingerprint Identification

In a particularly interesting project, Joseph H. Wegstein, his Bureau colleague John F. Rafferty, and Walter J. Pencak from the Federal Bureau of Investigation described a procedure for computing a set of numerical descriptors that identify a single fingerprint.[307]

The work of Wegstein, Rafferty, and Pencak was continued nearly a decade later with even more powerful tools. Raymond T. Moore and James R. Park developed an economical, semiautomatic device that could record information from low-quality fingerprints such as those often found at the scene of a crime. They called the device a 'Graphic Pen'. In the hands of a trained operator, the computerized sensor provided digital information on the "minutiae" of the print—ridge endings and ridge bifurcations—for later comparison with FBI files.[308]

Center for Radiation Research (Carl O. Muehlhause, Acting Director).

The Center for Radiation Research was newly created in 1968. It was formed by combining the Radiation Physics Division, formerly led by H. William Koch—who had recently departed to the American Institute of Physics—and the Reactor Radiation Division, headed by Muehlhause. The principal driving force in its formation was the desire to centralize the management of all the Bureau's major radiation-producing facilities—a newly commissioned 10 megawatt nuclear research reactor, a 100 MeV linear accelerator, various radioactive sources, a 4 MeV Van de Graaff accelerator and a synchrotron. This array of equipment could hardly have been assembled without the spacious environment provided by the new Gaithersburg site.

Because of the relative expense and scarcity of the center's machines, most were regarded as national facilities, to be used as much by scientists outside NBS as by the Bureau staff itself. The synchrotron, a modification of a small betatron-type electron

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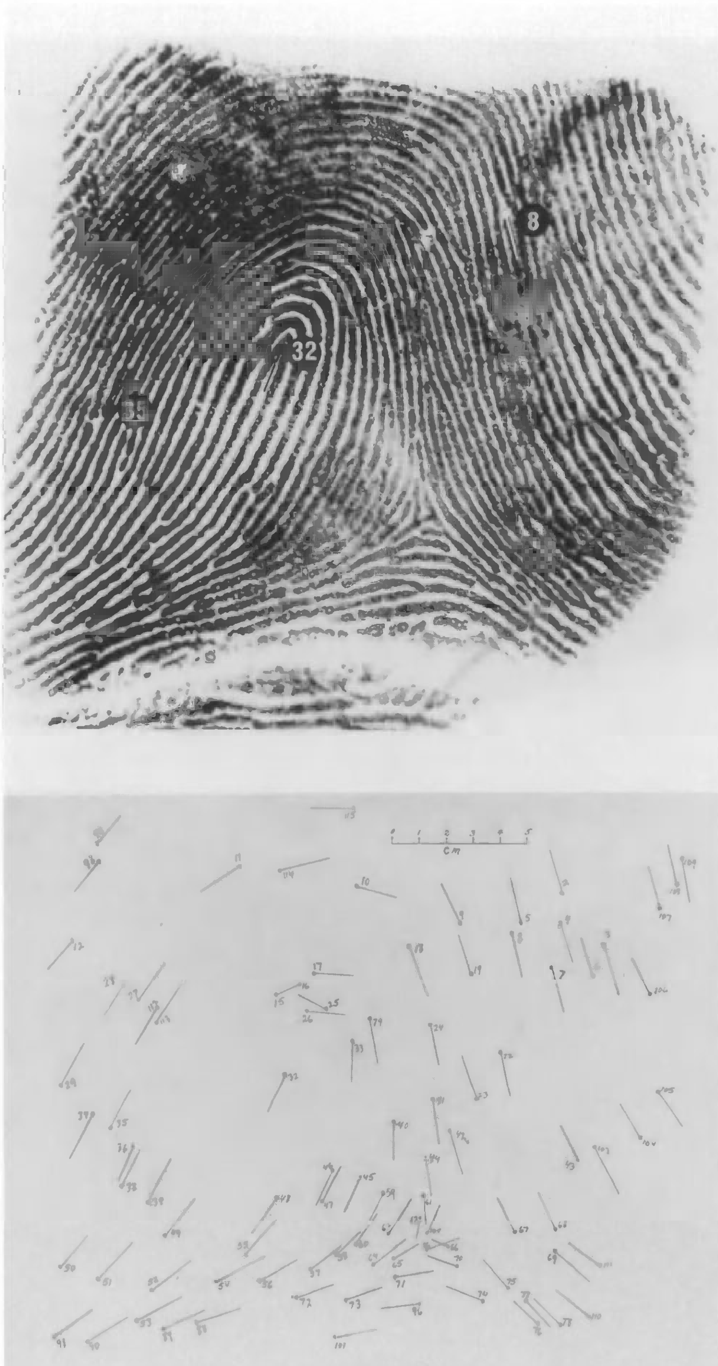
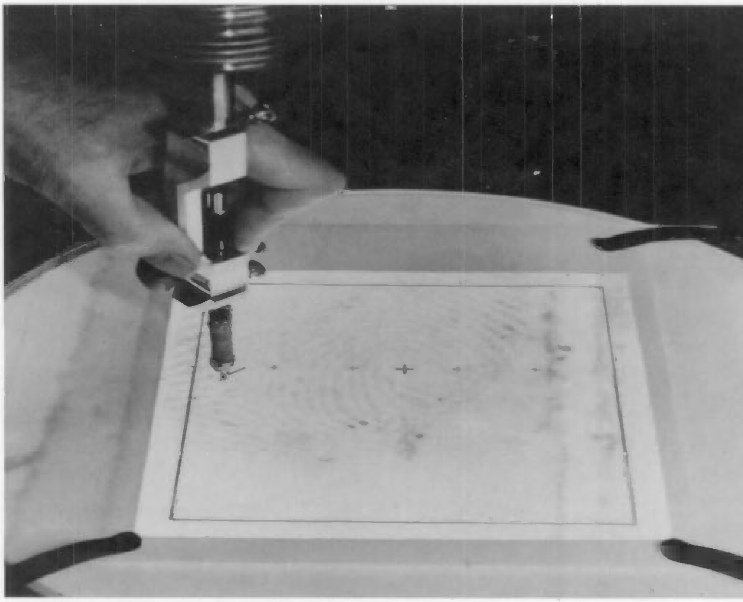
[306] R. W. Lee and R. W. Worral, "Electronic composition in printing," *(Proceedings of a symposium held at NBS,* Gaithersburg, MD. June 15-16, 1967), *NBS Special Publication 295,* February 1968, 133 pp.

[307] J. H. Wegstein, "A computer oriented single-fingerprint identification system," *NBS Technical Note 443,* March 1968. See also J. H. Wegstein, J. F. Rafferty, and Walter J. Pencak, "Matching fingerprints by computer," *NBS Technical Note 466,* July 1968.

[308] R. T. Moore and J. R. Park, "The Graphic Pen, an economical semiautomatic fingerprint reader," *Proc. 1977 Carnahan Conf. on Crime Countermeasures, Carnahan House, Lexington, Kentucky, April 6-8, 1977,* pp. 59-62.



In research sponsored by the Federal Bureau of Investigation, NBS Information Processing Technology Division scientists prepared a fingerprint (upper portion of photo) for classification and identification by marking its ridge endings and bifurcations on an overlay (lower portion of photo). The system provided descriptors for fingerprint details based on direction and location. The descriptors could be obtained, sorted, and matched with others by computer.



In a refinement of the work shown in the previous illustration, the Graphic Pen, a semiautomated device for marking the fine details of a fingerprint on an overlay, was developed to record fingerprint details.

accelerator, was moved from the Connecticut Avenue site.[309] Its primary use was as a source of far-ultraviolet radiation; although operated by the Center for Radiation Research, its main user group was the Far Ultraviolet Physics Section of the Atomic Physics Division.

Calibration Services

The need for standards in the areas of neutron physics, radioactive samples, and beams of x rays, gamma rays and electrons was large and growing in 1968. Consequently, the Center offered calibration services in all these fields. NBS Special Publication 250, *Calibration and Test Services of NBS,* listed services in neutron physics (neutron-source emission rate, neutron dosimeters, and neutron irradiation of test foils), radioactivity (both liquid and solid sources of alpha, beta, and gamma emitters), and x rays and gamma rays (measuring instruments, sources, and dosimeters).

Attached to the Center Office were a radiation theory group, whose research benefited the whole Center, and a health physics group, which had responsibility for

[309] "NBS Installs Synchrotron at Gaithersburg Laboratories," *NBS Technical News Bulletin*, Vol. 53, January 1969, pp. 4-5.

the safe utilization of sources of ionizing radiation. Typical radiation-theory research projects included the following:

Radiation Theory

As part of the Center service to users of radiation sources, Charles M. Eisenhauer utilized scattering theory to derive expressions for the radiation flux of gamma rays originating from a point source and singly scattered in air.[310]

Leonard C. Maximon developed analytic expressions for the production of an electron-positron pair in a Coulomb field, using the Born approximation to derive the cross section.[311]

Michael Danos and his colleagues Walter Greiner, of the Institut für Physik at the University of Frankfurt in Germany, and C. Byron Kohr, of the University of Maryland, described a static theory of the giant quadrupole resonance in deformed nuclei.[312] The authors stated that, in view of the great success of the hydrodynamic model of the giant dipole resonance in predicting its details, it appeared useful to press the model even further.

Irradiation of Foods

The radiation processing of foods, a technique important for the purification and durability of comestibles, required careful regulation of sources and dosages. H. William Koch and Elmer H. Eisenhower discussed the various criteria used for this type of irradiation.[313] Of special importance in their discussion was limiting any radioactivity induced in the target foods to negligible levels. The safety and efficacy of the radiation-processing technique was still debated publicly as this history was written.

Reactor Radiation Division (Robert S. Carter, Acting Chief).

The NBS nuclear reactor achieved criticality on December 7, 1967, following 9 years of planning and 4 years of construction.[314] It took another year for the reactor to achieve its full capabilities—a power level of 10 MW, a flux of 10^{14} neutrons/(cm^2 s), filtered neutron beams, intermediate-energy standard neutron field, neutron diffractometers, neutron radiography, time-of-flight neutron spectrometer, and neutron

[310] C. Eisenhauer, "Gamma radiation fluxes near a ground-air interface using an image source technique," *Nucl. Sci. Engr.* **32**, 166-177 (1968).

[311] L. C. Maximon, "Simple analytic expressions for the total Born approximation cross section for pair production in a coulomb field," *J. Res. NBS* **72B**, No. 1, 79-88 (1968).

[312] M. Danos, W. Greiner, and B. C. Kohr, "Static theory of the giant quadrupole resonance in deformed nuclei." *Phys. Rev.* **151**, No. 3, 761-772 (1966).

[313] H. W. Koch and E. H. Eisenhower, "Radioactivity criteria for radiation processing of food," Chapter 7 in *Radiation Preservation of Foods*, pp. 87-108 (Advances in Chemistry Series **65**, Am. Chem. Soc., Washington, DC, 1967.)

[314] "NBS Reactor Achieves Criticality," *NBS Technical News Bulletin*, Vol. 53, March 1968, p. 50.

In 1963 heavy machinery moved great quantities of earth to make way for construction of the NBS research reactor. The nearby farm buildings emphasize the change in character brought by NBS to Gaithersburg, Maryland.

irradiation and separation facilities.[315] Tawfik M. Raby was Acting Chief of Reactor Operations.

The division offered calibration services for neutron sources and instrumentation, as well as neutron irradiation of foils.

An Ethic of Collaboration

An explicit aim of the division was to encourage collaborative reactor projects with users from outside NBS. To prepare for the time when the NBS reactor would become available, the division staff had collaborated with outside groups for some time. In one of these collaborative efforts, John J. Rush performed an experiment with H. E. Flotow, D. W. Connor, and D. L. Thaper, colleagues from Argonne National Laboratory in Illinois. The group used cold neutrons from the CP-5 research reactor at Argonne to study the vibrational spectra of yttrium and uranium hydrides.[316] They observed inelastic (energy-gain) scattering of the neutrons, obtaining spectra that were split into two bands—a higher-energy optical band presumably arising from optical hydrogen vibrations, and a lower-energy band which they ascribed to metal-atom vibrations.

[315] H. L Mason and Iris M. Lloyd, editors, "Special Technical Facilities at the National Bureau of Standards," *NBS Special Publication 413,* March 1976, pp. 30-34.

[316] J. J. Rush, H. E. Flotow, D. W. Connor, and D. L. Thaper, "Vibration spectra of yttrium and uranium hydrides by the inelastic scattering of cold neutrons," *J. Chem. Phys.* **45**, No. 10, 3817-3825 (1966).

Vernon W. Myers had utilized the Brookhaven National Laboratory cold-neutron source in late 1966 to obtain information on inelastic scattering in gray tin.[317] Later, he provided solutions of the time-dependent Klein-Gordon and Dirac equations for the motion of a charged particle in a classical, uniform electrostatic field.[318]

Neutron Cross Sections

The *Second Conference on Neutron Cross Sections and Technology* was held at a Washington, DC, hotel in March 1968. The 123 papers given at the meeting filled the two-volume *NBS Special Publication 299,* edited by David T. Goldman.[319] The conference was useful in promoting dialog between basic researchers and those performing applied radiation tasks. The eight sessions were intended to address the need for accurate measurements, theoretical and experimental methods, and applications.

Linac Radiation Division (James E. Leiss, Acting Chief).

The Linac Division operated a linear-accelerator facility which provided high-intensity beams of electrons, photons, and neutrons. The beam energy was continuously variable over the range 10 MeV to 150 MeV, with a spread of 2 %. The pulse length could be varied from 1 ns to 5 μs, with a repetition rate as high as 720 pulses/s. Four experimental rooms were available; users could occupy any room not under irradiation.[320]

The division also offered programs on instrumentation, headed by Louis Costrell; photonuclear physics, under Everett G. Fuller; and electronuclear physics, under the leadership of Samuel Penner.

Many applications were possible using the Linac—from neutron cross section studies to electron and photon dosimetry, biochemical radiolysis, and photonuclear physics experiments. In the following, we note some of these applications.

Detector Development

John W. Lightbody, Jr. and Samuel Penner described a 12-channel array of lithium-drifted silicon detectors to be used for detecting high-energy electrons in the focal plane of a magnetic spectrometer.[321] The system exhibited good momentum resolution and stable efficiency.

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[317] V. W. Myers, "Inelastic scattering of cold neutrons in polycrystalline gray tin," *J. Chem. Phys. Solids* **28**, 2207-2210 (1967).

[318] V. W. Myers, "Solutions of the time-dependent Klein-Gordon and Dirac equations for a uniform electric field," *J. Res. NBS* **72B**, No. 1, 37-42 (1968).

[319] D. T. Goldman, editor, *Neutron cross sections and technology,* Proceedings of a conference held in Washington, DC, March 4-7, 1968, NBS Special Publication 299, September, 1968, Vol. 1, 660 pp., Vol. 2, 2718 pp.

[320] H. L Mason and Iris M. Lloyd, editors, "Special Technical Facilities at the National Bureau of Standards," *NBS Special Publication 413,* March 1976, pp. 2-3.

[321] J. W. Lightbody, Jr. and S. Penner, "A 12-channel semiconductor counter system for the NBS electron scattering spectrometer," *IEEE Trans. Nucl. Sci.* **NS-15**, 419-425 (1968).

Photodisintegration

Calculations of two- and three-body photodisintegration cross sections for ^3H and ^3He were performed by James S. O'Connell and Francisco Prats.[322] As the ground-state wave function, they used an exact solution of the three-body Schrödinger equation.

Photonuclear Data Center

Members of the staff of the Photonuclear Physics Section of the division had established a photonuclear data center, in which data on photonuclear reactions were collected. An index to more than 600 publications, organized by element and isotope, was published in 1966.[323]

Nuclear Radiation Division (Harry H. Landon, Acting Chief).

Neutron physics, headed by Landon; radioactivity, under Wilfred B. Mann; and nuclear spectroscopy, led by Raymond W. Hayward, were active areas of research within the Nuclear Radiation Division during 1968.

Scattering

The backscattering of alpha particles from metallic surfaces was the focus of a project by J.M. Robin Hutchinson, Carol R. Naas, Delores H. Walker, and Wilfred B. Mann.[324]

Nucleon-Field Interactions

Raymond W. Hayward prepared a discussion of the interactions of nuclei with electromagnetic fields for the Condon-Odishaw *Handbook of Physics.*[325]

Applied Radiation Division (Joseph W. Motz, Acting Chief).

The Applied Radiation Division calibrated equipment for the detection of alpha, beta, gamma and x-ray radiation. In addition, the staff worked in the area of dosimetry under the leadership of Robert Loevinger.

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[322] J. S. O'Connell and F. Prats, "Photodisintegration of the trinucleon system in a separable potential model," *Phys. Lett.* **26B**, No. 4, 197-200 (1968).

[323] *"Photonuclear Data Index,"* prepared by the NBS Photonuclear Data Group (N. V. Baggett, Theresa M. Collins, Everett G. Fuller, Julia C. Holland, John H. Hubbell, and James S. O'Connell), *NBS Miscellaneous Publication 277,* April 1966.

[324] J. M. Robin Hutchinson, Carol R. Naas, Delores H. Walker, and Wilfred B. Mann, "Backscattering of alpha particles from thick metal backings as a function of atomic weight," *Intern. J. Appl. Radiation Isotopes* **19**, No. 6, 517-522 (1968).

[325] R. W. Hayward, "Nuclear electromagnetic radiation," Chapter 6 in *Handbook of Physics, Second Edition, Part 9,* Nuclear Physics, E. U. Condon and H. Odishaw, eds. pp. 9-172 to 9-194 (1968).

Electron Interactions and Detection

Samuel E. Chappell, Jimmy C. Humphreys, Joseph C. Motz, Martin J. Berger, and Stephen M. Seltzer evaluated the response of silicon detectors to monoenergetic electrons.[326]

Measurement of the energy and the current of accelerated electron beams was simplified by a device that incorporated a thin aluminum foil placed in the beam. Developed by Motz and Julian H. Sparrow, the device was found to yield accurate energy measurements over the range 50 keV to 500 keV.[327]

Stopping Power

Additions to existing tabular data on stopping power relative to protons, mesons, and electrons were provided by Martin Berger and Stephen Seltzer. They also corrected earlier data on electrons in muscle and bone.[328]

Summary

This chapter has provided a glance at only a tiny fraction of the numerous projects taking place in the technical divisions of NBS during the last years of Allen Astin's service as Director. Nevertheless the list illustrates the intense scientific nature of the Bureau at that time. It also provides a measure of the strength of the Bureau's technical staff, many of whom were world leaders in their specialties.

As a look at Appendix K shows, changes in the formal structure of NBS occurred frequently. The main lines of research, however, changed less frequently and usually in an evolutionary way. Particular lines of study opened and matured over periods of time that were as likely to be measured in decades as in years. New programs or lines of inquiry were often undertaken through the hiring of new staff members rather than through shifts of interest on the part of long-time employees.

In the following chapters, we trace the progress of some of the projects described in this section, although more frequently we introduce work that has not previously been discussed.

[326] S. E. Chappell, J. C. Humphreys, J. C. Motz, M. J. Berger, and S. M. Seltzer, "Response of silicon transmission detectors to monoenergetic electrons," *IEEE Trans. Nuclear Sci.* **NS-15**, No. 3, 359-362 (1968).

[327] J. W. Motz and J. H. Sparrow, "A simple device for the energy and current measurement of an accelerator electron beam," *Record of the IEEE 9th Annual Symposium on Electron, Ion, and Laser Beam Technology, May 9-11, 1967,* Berkeley, *California* (San Francisco: San Francisco Press, 1967) pp. 34-41.

[328] M. J. Berger and S. M. Seltzer, "Aditional stopping power and range tables for protons, mesons, and electrons," *NASA-SP,* 3036 (1966).

THE END OF AN ERA

While the Bureau staff busied itself with its manifold duties during 1968, it awaited the coming change in its leadership. When Astin, with typical concern for order and planning, had made known his intention to resign after the coming presidential election, there was a strong sense among NBS employees that the agency was witnessing the end of an era.

Allen Astin had been appointed Director by President Harry Truman; he had served with distinction under Presidents Eisenhower, Kennedy, and Johnson as well. Under Astin, the Bureau had seen the passing of the remnants of the World War II projects from its organization, had heard the accusations of villainy in the AD-X2 affair and the vindication of its integrity that followed, and had enjoyed the flowering of a re-invigorated staff utilizing the "new science and the new scientists" sought by Condon but brought to NBS mostly by Astin.

Astin earned many laurels during his long career. His numerous awards for scientific and administrative service to the U.S. government included *His Majesty's Medal for Service in the Cause of Freedom* (1947), the *Presidential Certificate of Merit* (1948), the *Department of Commerce Gold Medal* (1952), the *Eli Whitney Memorial Award* of the *American Society of Tool Engineers* (1960), the *Scott Gold Medal* of the *American Ordnance Association* (1962), the *Rockefeller Public Service Award* (1963), the *ASTM Award to Executives* (1965), the *Standards Medal* of the *American National Standards Institute* (1969), and a *Certificate of Commendation* presented jointly by the Nation's 50 Governors.

Astin decided to remain as Director through the 1968 elections despite the possibility of the loss of his choice as successor—Lewis Branscomb—should the Republicans take over the Executive Branch of the government. There would be no "emeritus advisor" role for Astin to circumvent the legitimate process of succession.

And there would be no machinations to pre-empt the normal course of events by Branscomb, either. He would take what came. Never mind that—married to an active worker for the Democratic Party—Branscomb might be passed over, should the White House be captured by a Republican. In any case, his creation, the Joint Institute for Laboratory Astrophysics, still attracted his restless interest. JILA, only four years old, was quickly maturing as a scientific organization. It was becoming a more potent force in its field with each passing year. There was plenty to do in Boulder.

Director Astin gave no indication, during his last months in office in 1968 and 1969, that he was a man fatigued by a full career of service. He continued his long-term efforts to fine-tune NBS for smooth operation:

- In February of 1968, he directed the Cryogenics Division to report to the Director of the Institute for Basic Standards.[329] In June, he established the position of Deputy Director, IBS/Boulder, with Bascom W. Birmingham as the incumbent.[330] He also named Ernest Ambler to the post of Director, IBS.

[329] NBS Admin. Bull. 68-22, 21 Feb 68.

[330] NBS Admin. Bull. 68-118, 24 June 68.

- Also in February 1968, he directed the Physical Chemistry Division to report to the Director of the Institute for Materials Research.[331] He named John D. Hoffman as Director, IMR.
- In June of 1968, Astin appointed Lawrence M. Kushner to the post of Director of the Institute for Applied Technology.[332] By the following January, Astin had named Kushner to the position of Acting Deputy Director of NBS to replace Irl C. Schoonover, who retired after 41 years of service to the Bureau (1928-1969).[333] To take Kushner's place, Astin appointed Howard E. Sorrows, previously Deputy Director of the Institute for Materials Research, to the position of Acting Director of the Institute for Applied Technology.
- The NBS/General Services Administration Test and Evaluation Division, formed in 1966 to test items purchased by the GSA and other government agencies, was transferred bodily by Astin to the GSA. This action brought to a close a million-dollar-a-year activity that the Bureau regarded as barely relevant to its mission.
- In July 1968 Astin acted to create an Equal Employment Opportunity office for NBS. Donald G. Fletcher, Robert F. Bain, and Karl E. Bell were appointed to a committee to receive any staff complaints of discrimination on the basis of race, sex, creed, or national origin.[334]
- The Center for Radiation Research was created by Astin during 1968 as well, with Carl O. Muehlhause appointed as its first Director.
- The Center for Computer Sciences and Technology, established in 1966 in response to the "Brooks Act" (PL 89-306, 1965), was made a separate organizational entity late in 1968. Astin asked Herbert R.J. Grosch to continue as its Director.
- One of Astin's last major organizational moves occurred late in 1968 when he created the office of Associate Director for Information Programs. Edward L. Brady, former Chief of the Office of Standard Reference Data, was named Associate Director. Brady's responsibilities included the following:
    - Supervision of the OSRD—then headed on an Acting basis by David Lide, Jr.
    - The Clearinghouse for Federal Scientific and Technical Information, located in Springfield, Virginia and headed by Hubert E. Sauter.
    - The Office of Technical Information and Publications, under W. Reeves Tilley.
    - The Library Division headed by Elizabeth L. Tate.
    - The Office of Public Information, with A. Victor Gentilini as Chief.
    - The Office of International Relations under Ladislaus L. Marton.

[331] NBS Admin. Bull. 68-22, 21 Feb 68.

[332] NBS Admin. Bull. 68-113, 17 June 68.

[333] Kushner's initial responsibilities as Deputy Director included management of the Instrument Shops Division, the Measurement Engineering Division, and the Offices of Industrial Services and Engineering Standards Liaison. By mid-1969, Astin had transferred the Instrument Shops Division to the Institute for Applied Technology.

[334] Memo to all employees, 12 July 68.

Preparing to retire as Director on August 31, 1969, Allen Astin was still responsible for presenting the NBS budget before Congress one last time. This last appearance—May 13, 1969—might have become the occasion for a brief reference to Astin's long and faithful service.[335] But as had been the case since 1963, the budget hearing was chaired by Congressman John Rooney. In contrast to the civil—even friendly—manner of predecessors such as Prince Preston of Georgia or George Andrews of Alabama, Mr. Rooney consistently presented a less conciliatory demeanor to all public servants who appeared before him.

Allen Astin had suffered at Congressman Rooney's seances as much as any agency head but, characteristically, he suffered in silence. Even during his last appearance before the subcommittee Astin was calm, turning the other cheek when his tormentor attacked. He presented an austere budget of some $38.7 million, cut by the Department of Commerce and by the Bureau of the Budget from an initial request of $48.1 million. Over and over again, Congressman Rooney asked Astin to repeat the two numbers, as if to stress the enormity of Astin's sin in requesting more money than even the spendthrift Executive Branch could countenance.

In connection with a proposed high-purity materials preparation facility, Astin mentioned that day the need for "clean rooms" where super-pure materials could be processed; Mr. Rooney saw this request as ". . . incongruous that you should be talking about cleanliness. I can remember when nobody washed the windows out there at Connecticut Avenue. Do you remember that, Doctor?"

Perhaps as something of a farewell to Astin—certainly not because the topic was relevant to the day's discussion—Rooney called to mind that day another incident from the past. A year or two previously, a specialized painting job on one of the Bureau buildings had been performed inadequately and—at no cost to the government—had been repaired by the contractor when the fault had been discovered. "Can you approximate the amount of cost to the taxpayer as a result of this fiasco, regardless of who was to blame for it?," demanded the Congressman. Astin patiently provided the subcomittee with NBS records that showed no cost to the taxpayer. However, if the citizens of Brooklyn needed further proof of the concern felt by their elected representative for their pocketbooks and for their government's integrity, Mr. Rooney provided it one more time.

Astin had begun his day's testimony by saying:

> This is probably the last time I shall have the privilege of appearing before this committee since I have announced plans to retire at the end of August. I would, therefore, like to express my thanks and appreciation for your thoughtful consideration of my budget requests over the past 17 years.

If Congressman Rooney—or any of the other subcommittee members, for that matter—felt that Astin's nearly 40 years of public service merited thanks that day, the record fails to show it. Nor does the historical record anywhere indicate whether Allen Astin indulged himself with a small celebration late in the day on May 13, 1969.

[335] 1970 House Subcommittee Hearings, May 13, 1969, p. 895.

Lewis Branscomb, the heir-apparent to the directorship of NBS, was busy during 1968 and 1969, too. In addition to his duties as chairman of JILA and Chief of the Laboratory Astrophysics Division, he served as adjunct professor to the University of Colorado. He also made several contributions to the scientific literature: he edited a conference proceedings that included his own paper, a summary of atomic collision processes of importance to astronomy;[336] he produced a historical review of the field of electron, atomic, and molecular physics;[337] he wrote a critique of quality control in the publication of the results of scientific measurements;[338] with Robert E. LeLevier, a colleague from Rand Corporation in Santa Monica, CA, he published a theoretical discussion of the ion chemistry involved in the concentration of mesospheric electrons;[339] and with Gary C. Tisone, a Research Associate in the Joint Institute for Laboratory Astrophysics, he described the results of electron detachment experiments on H^- and O^-.[340]

Branscomb's interests clearly reached beyond the laboratory to national topics, too, as evidenced by an article in Physics Today that asks the reader, "Please imagine that it is January 1980 and this talk is entitled 'Retrospective Look at How Physics has Changed in Relation to Society in the Past Twelve years.'"[341] He also continued his service as a member of President Johnson's Science Advisory Committee.

Outside NBS, the situation in national affairs was dismal. Many events conspired to touch the Nation with a sense of impending trouble—President Johnson's March 1968 announcement that he would not be a candidate for the office of President, the political rise and untimely snuffing out of the life of Robert Kennedy, the nomination of Hubert Humphrey for President in a violent Democratic convention, the accession of Richard Milhous Nixon and Spiro Theodore Agnew as the Republican Party's presidential team, the public distress arising from the war in Vietnam, and the loss by assassination of Martin Luther King, Jr.

But the national unease contrasted in a curious way with the eager anticipation at NBS for a leader who was worthy to don the mantle being shed by Allen Astin.

How strange the path ahead was to become, for the Nation and the Bureau, no one could possibly know in 1968.

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[336] L. M. Branscomb, "The role of atomic collision processes in astrophysics," Chapter in *The Physics of Electronic and Atomic Collisions: Invited papers from the Fifth International Conference, Leningrad, U.S.S.R., July 17-23, 1967,* L. M. Branscomb, ed., (Boulder, CO: Joint Institute for Laboratory Astrophysics, University of Colorado, 1968), pp. 12-31.

[337] L. M. Branscomb, "Twenty years of physics: atoms, molecules and electrons," *Physics Today* **21**, No. 5, 36-39 (1968).

[338] L. M. Branscomb, "The misinformation explosion: Is the literature worth reviewing?" *Sci. Res.* **3**, No. 11, 49-52 (1968).

[339] R. E. LeLevier and L. M. Branscomb, "Ion chemistry governing mesospheric electron concentrations," *J. Geophys. Res.* **73**, No. 1, 27-41 (1968).

[340] G. C. Tisone and L. M. Branscomb, "Detachment of electrons from H^- and O^- negative ions by electron impact," *Phys. Rev.* **170** No. 1, 169-183 (1968).

[341] L. M. Branscomb, "Physics and the nation in a crystal ball," *Physics Today* **21**, No. 8, 23-28 (1968).

CHAPTER TWO

BRIGHT PROSPECTS FOR NBS (August 1969–May 1972)

It was a terrible year for America, 1968, but one of great expectations for the National Bureau of Standards. The paradoxical existence of an optimistic attitude among the staff of NBS—arising in the midst of a mordant pessimism for the future of their country among the American public—had its resolution in the anticipation of vigorous new leadership for the Bureau. True, the NBS budget was confining; it was necessary for many a manager to seek funding from sources outside of Congress in order to reach for new programs or, sometimes, to support existing ones. Also true, the state of the scientific equipment was precarious in many a Bureau laboratory. But the staff was strong, the laboratories themselves were modern, and the reputation of NBS for integrity and scientific capability was secure. Allen Astin had left a fine legacy.

The Bureau staff could not anticipate all the changes that were in store for their agency, although the signs were there to be seen. Public support of the scientific establishment was declining; the decrease was felt most keenly among those involved in fundamental studies. In response to that decline, there was a rising insistence on "relevance," the ability to justify projects in terms of immediate public benefits. Continually growing was the number of large programs created to address the troubles of a beleaguered American industry. The one change that was obvious was that Allen Astin was stepping down from his post of 17 years. The prospect that a vigorous new leader could magnify the gains achieved under Astin was exciting.

A NATION IN DISTRESS

The Nation saw, in 1968, an avalanche of misery of the sort that it had felt in 1963 when the vigorous life of John Kennedy was stopped in an instant by an assassin's bullet. Historian James Patterson called 1968 "the most turbulent year" in the period 1945-1974.[1]

The year began with the Tet offensive in Vietnam. President Lyndon Johnson had seen the number of U.S. military personnel in Vietnam mushroom from the 17,000 "advisors" of Kennedy's truncated term to 500,000 troops.[2] The stepped-up American presence was certain, said General Westmoreland, to give America a "light at the end of the tunnel." Surely, such a large military force would make short work of an unpopular conflict. Just in time, too, for war protesters already were tramping the streets of the Nation's capital.[3]

[1] Of many chronicles of the post-WWII/Vietnam era, one by James T. Patterson, *Grand Expectations: The United States, 1945-1974* (New York: Oxford University Press, 1996) is among the most thorough. The quote is from the title of Chapter 22.

[2] Ibid., p. 595.

[3] Ibid., see photos following p. 558.

The North Vietnamese chose the time of Tet, the holiday of the lunar new year in January, to show their determination to withstand the American escalation. In one of many simultaneous, bloody attacks, soldiers stormed the U.S. embassy in Saigon, breaching the heavy walls of the compound and leaving their dead and dead American defenders on the lawn. With that concerted, multi-pronged assault, the North Vietnamese quenched the light at the end of the tunnel—the Vietnam war was obviously far from over.

On March 31, 1968, a downhearted Lyndon Johnson announced to the American people that he was halting the bombardment of North Vietnam. He also told a stunned radio audience, "I shall not seek, and I will not accept, the nomination of my party for another term as your President."[4]

The national disasters continued in April of 1968. Martin Luther King, who nearly single-handedly had kept heated racial tensions from exploding, was cut down in Memphis by an assassin. Before that day was out, fires were burning in a dozen American cities. Riots, arson, and mayhem killed or injured more than 20,000 people within a few days. The Nation's capital itself saw hundreds of fires and ten killings.[5]

Robert Kennedy was a victim in 1968 as well. Mounting a vigorous campaign for President even before Johnson's withdrawal, Kennedy rallied the Nation to resist the forces of anarchy, racial discrimination and despair. In June, after he completed a speech at a Los Angeles hotel and was leaving the scene, Kennedy, too, was shot and killed.[6]

There were still 6 months of 1968 for the Nation to endure. They were not happy months.

The Democratic national convention of 1968, which took place in Chicago during August, was marred by Mayor Richard Daley's heavy-handed response to ever-present anti-war demonstrators. Along with bystanders, reporters, photographers—even medical personnel—the demonstrators were pursued, clubbed, tear-gassed, and arrested. The scene turned many in the watching American public away from the Democratic presidential ticket of Hubert Humphrey and Edmund Muskie and towards the Republican candidates, former Vice-President Richard Nixon and Maryland Governor Spiro Agnew. The stage was set for more nasty years still to come.

Richard Milhous Nixon

Richard Nixon, as a young lawyer in California, had no political plans. Certainly, he had no program that would carry him to the White House. An outstanding student at Whittier College, a small Quaker school, Nixon received a scholarship to the law school at Duke University, graduating third in his class of 25 with an LLB degree in 1937. By 1940, he was settled in a law practice. In June of that year he married Thelma Patricia Ryan, whom he met during his membership in a little theater group.

[4] Ibid., p. 685.

[5] James MacGregor Burns, *Crosswinds of Freedom,* (New York: Vintage Books, 1990) p. 413.

[6] Ibid., p. 414.

Nixon's low-key life changed with America's entry into World War II. He served in the U.S. Navy from 1942-46, returning to California just in time for the Republican party to recruit him as an opponent to Congressman Jerry Voorhis. Quickly finding a campaign technique that would serve him well in future races, he attacked Voorhis as a tool of the Communist Party. The accusation, loosely based but effective, combined with Nixon's youth, his wartime service, and his excellence at debate to elect him to the U.S. Congress, Class of 1946, where he joined a Republican majority.

Nixon served vigorously in the House. He helped craft the Taft-Hartley labor bill as a member of the Committee on Education and Labor, and, as a member of the Committee on Un-American Activities, he helped convict suspected spy Alger Hiss of perjury. He found Congressional service much to his liking and eagerly took the opportunity to campaign against Helen Gahagan Douglas for the Senate in 1950.

A scarcely modified "She's-A-Communist-Tool" campaign, coupled with an increasingly effective speaking ability, elected Nixon to the U.S. Senate, where he carried the party message nation-wide with perhaps 200 speeches to the faithful during 1951 and 1952. The party, grateful and impressed, looked kindly upon the choice of Nixon as the vice-presidential candidate to accompany the 1952 presidential bid of Dwight David "Ike" Eisenhower, the intensely popular leader of America's military forces in Europe during World War II.

Nixon's first brush with political disaster, a revelation of secret political funds donated by wealthy supporters, occurred during the 1952 campaign. Nixon overcame the potentially lethal problem by dint of a masterful speech; he remembered with rancor, however, certain "enemies"—particularly some aggressive members of the press who questioned his ethics.

Eisenhower and Nixon defeated Illinois ex-Governor Adlai E. Stevenson and Alabama Senator John Sparkman by nearly 6 million votes of the 60 million cast. Ike, a political neophyte, proved to be a forceful president, though his health began to fail before his first term was complete. He was instrumental in bringing the Korean War to a cease-fire in July 1953, and he offered quiet support to those who eventually brought low his fellow Republican, Senator Joseph McCarthy. Ike willingly fought the Cold War, endorsing the development of thermonuclear weapons and an aggressive intelligence effort. Despite suffering a heart attack in 1955, he easily won re-election to the presidency in 1956. It was said that Eisenhower was not especially fond of Nixon. On two occasions the President offered Nixon a Cabinet post, but Nixon opted to remain as Vice President.[7] The 1956 Eisenhower-Nixon margin of victory over Stevenson and Tennessee Senator Estes Kefauver was larger than that enjoyed in 1952.

During his two terms as Vice President, Nixon was increasingly called upon to assist Ike with his ceremonial functions. Besides his heart attack in 1955, the war hero suffered an ileitis attack in 1956 and a stroke in 1957. Nixon visited some 56 countries as Vice President, including notable visits to Venezuela and the U.S.S.R. In Venezuela, Nixon's cavalcade was disrupted by local insurgents, including members of the local

[7] Stephen Ambrose, *Eisenhower: Soldier and President* (New York: Simon & Schuster, 1990), pp. 400-405.

Communist Party; Nixon displayed courage in the face of the attackers, and the world noticed. In Moscow, Nixon confronted Nikita Krushchev during a visit to a kitchen-appliance booth at a trade fair, "jawing" with the old Communist fearlessly. Again, the world noticed.

Nixon's string of electoral victories was interrupted, however, when he ran for President of the United States and, later, for Governor of California. The Nixon-Henry Cabot Lodge presidential ticket lost to John F. Kennedy and Lyndon B. Johnson in the 1960 presidential campaign; then Nixon lost again, to Edmund G. "Pat" Brown, in the 1962 California gubernatorial race. Disappointed and "through with public office" Nixon moved to New York, then called one last press conference to chastise some of his enemies in the press, announcing, "You won't have Nixon to kick around anymore, because this is my last press conference."

However, as noted above, 1968 was an unusual year. Perhaps longing for the bright light of politics, Nixon secured so many primary presidential votes in 1968 that his early opponent, George Romney, Governor of Michigan, withdrew from the race for the Republican nomination. Then Nixon outlasted Nelson Rockefeller and Ronald Reagan to win his party's nomination. He and Maryland Governor Spiro Agnew won the election over former Vice-President Hubert Humphrey and his running-mate, Senator Edmund Muskie, and over the surprisingly popular third-party candidates, Alabama Governor George Wallace and Air Force General Curtis LeMay. Nixon didn't realize at the time that his real trouble was just beginning.

Facing Adversity

President Nixon was beset by a host of problems as soon as he took office. The list could have served as a medical report for an ailing nation, beginning with the deep political turmoil described in the previous sections and including social inequities, growing inflation, increasing unemployment, a shaky stock market, and worsening international trade balances.

Vietnam, the Soviet Union, and China

International affairs interested Richard Nixon. He had seen the world as Vice President under Eisenhower, and he felt that—by relying on a mixture of toughness, understanding, and diplomacy—he could bring a new level of quiet to world disorder. His primary preoccupation, no doubt, was Vietnam, although he was confident that he could get results with the U.S.S.R. and China as well.

Nixon chose Henry Kissinger as his security advisor. Kissinger, a former professor of government at Harvard, was anxious to practice his craft in the international arena; Nixon gave him his chance.

Nixon and Kissinger—both secretive men, much given to manipulation and craving of public acclaim—made an odd couple, occasionally working at cross-purposes. Yet they gradually brought about a marked reduction of the American presence in Vietnam and improved relations with both the Soviet Union and China.

Nixon had a "secret plan" to end the war in Vietnam, he told audiences while campaigning for president in 1968. This, like other claims by other men, was not a statement that should be taken literally. However, Nixon confided to aides that he felt confident in his ability to bring the North Vietnamese to the bargaining table. He called his method the "madman theory"; known to be a rabid anti-communist, he would frighten the enemy with the specter of nuclear disaster. And in truth, he and Kissinger were always ready with bombs when persuasion was needed in Vietnam—and occasionally in Cambodia and Laos, too.

As they stepped up the bombing war in Vietnam, Nixon and Kissinger reduced the number of American soldiers on the ground. In June 1969 Nixon announced the withdrawal of 25,000 troops. The South Vietnamese correctly surmised that support for their cause was diminishing within the U.S. government. Antipathy for the war within the American public became still more pronounced.

In February 1972, Nixon traveled to China, seeking improved relations with the Communist giant. The trip was largely for show, as he gained no concessions from his hosts; in fact, he volunteered that America would reduce the size of its military force in Taiwan, thus weakening the position of the island country in the United Nations.

In May 1972, as Lewis Branscomb was departing from the National Bureau of Standards, President Nixon paid a visit to Moscow to sign—with his counterpart, Leonid Brezhnev—a *Strategic Arms Limitation Treaty* and another document restricting the use of anti-ballistic missiles. The treaties offered an improvement in communications between the two Cold-War enemies, if little in terms of actual arms reduction. Again, an ancillary deal actually went against the interest of the United States: large quantities of American grain were offered at bargain prices to the Soviets, thus reducing U.S. supplies and mildly aggravating inflation in America.

Domestic Issues

Nixon was not interested in social programs, or especially taken with domestic politics. He had derided Johnson's Great Society during his presidential campaign. Nevertheless, social troubles—indeed, troubles of many varieties, both domestic and international—abounded, and their cure would require vigorous action. Prodded by a largely progressive Democratic Congress, Nixon collaborated in the enactment of a considerable amount of social legislation during his first term in office. Included in the list were: an extension of the Voting Rights Act of 1965; funding for the war on cancer, for enhanced medical training, and for the arts; a ban on gender bias in higher education; greater support for those in poverty; creation of the Environmental Protection Agency and the Occupational Safety and Health Administration; and the Clean Air Act, the Federal Water Pollution Control Act, and the Consumer Product Safety Act.[8] This legislation affected the National Bureau of Standards both directly and indirectly, as we shall see.

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[8] James T. Patterson, *Grand Expectations*: Ch. 23.

Despite his participation in a program of social progress, the American public displayed decidedly mixed feelings towards President Nixon. The 1970 elections left the Congress securely in Democratic hands, and the public, finding it difficult to make ends meet and encouraged by a national press that was increasingly critical of the President, gave him little credit for his part in the new social legislation.

In August 1971, unable to ignore the Nation's economic ills, Nixon announced a *New Economic Policy.* He instituted a 90-day freeze on wages and prices, he ended the link between dollars and gold, and he placed a temporary 10 % surcharge on imports. These steps represented a radical departure from the Republican economic credo; they showed President Nixon to be, in fact, flexible in his economic thinking. The new policy included a promise to reduce Federal spending—a recurring Republican theme—and a proposal to eliminate 5 % of all Federal employment. The effects of these promises were quickly felt at NBS.

For purposes of Nixon's re-election in 1972, his New Economic Policy worked well. The national economy made a notable, though transient, recovery that fitted nicely with the President's statesmanlike performances in China and the Soviet Union. However, the underlying problems remained, to surface again during Nixon's second term.

The availability of energy for use in the United States became a visible problem during Nixon's presidency, too. The Arab oil-producing states, forced by a common war against Israel to cooperate, discovered that oil export prices and quotas could be powerful weapons in international affairs. Although the Arab countries occasionally returned to the self-defeating practice of unilateral action, by 1971 oil prices began a rise to levels never before seen. In the United States, oil consumption continued to increase despite presidential efforts to encourage conservation.

By virtue of tape recordings of White House conversations made public later, we know that President Nixon was preoccupied right from the time of his election in 1968 with plans for re-election to a second term in 1972. Nearly every move was scripted as much to improve the image of the Nixon administration as for its value to the Nation's welfare. During his second term, Nixon's determination to seek revenge for real and imagined political damage by those on his "enemies list" carried him well beyond the limits of ordinary political maneuvering.

A New Director for the National Bureau of Standards

In Gaithersburg, Maryland, and in Boulder, Colorado, the men and women of the National Bureau of Standards were well aware of the Nation's anguish. They were, after all, citizens, parents, husbands, and wives. Each was touched in various ways by the war, by the Nation's economic ills, and by racial conflict.

The U.S. Civil Rights Commission, studying the results of moving several government agencies from city locations to the suburbs, noticed that the National Bureau of Standards had lost an aggregate 73 black employees—while the overall employment rose by 125—when the Bureau headquarters was moved to "the sticks." The Commission suspected racial discrimination in housing, hiring, or both.[9] And discrimination there was.

The feeling in the air at NBS, however, was that good things were about to happen in 1968.

Allen Astin had made known in 1967 his plans to retire during 1969, when he would be 65 years old. He had served the Bureau and the Nation well for over 35 years—17 of them as NBS Director—at the time of his retirement. All of his years had been challenging and some of them were hard labor as well.[10]

Astin had seen—in many cases, had precipitated—the shift in Bureau work away from the military projects that had dominated NBS during World War II, leaving the agency more tranquil in spirit and more nearly supported by direct congressional appropriations than it had been for many years. About 80 % of Bureau funding came directly from Congress in 1968, twice the wartime percentages of 40 % or less.

Burned into Astin's memory was the AD-X2 travail. He had not only survived that ordeal but—because of his own exemplary behavior and that of the NBS staff throughout the incident—it had served to elevate beyond question the Bureau's reputation for accuracy and integrity.

Astin regarded as the capstone of his service to NBS his efforts to develop a mission statement for the Bureau and to advance a general recognition of its unique, triune role in American technological life:

1. To provide a complete and consistent system of physical measurements in harmony with the international system.
2. To provide essential services leading to accurate and uniform physical measurements throughout the United States.
3. To provide needed data on the properties of matter and materials of technological importance.

Astin communicated the ideas underlying the NBS mission repeatedly, often inserting them into his testimony before the House Appropriations Subcommittee that monitored the Bureau.[11]

As he entered his last year as director, Astin was happy that he could recommend a successor who showed such great promise.

[9] Leonard S. Rubinowitz, *Low Income Housing: Suburban Strategies*, (Cambridge, MA: Ballinger Publishing Co, 1974) p. 179.

[10] Besides the brief references in this volume, there are more detailed discussions elsewhere of Astin's difficult years. See, for example, Elio Passaglia, *A Unique Institution*, and *Science: Evidence, Truth and Integrity*, NBS Special Publication 690, January 1985.

[11] See, for example, House Appropriations Subcommittee hearings, March 28, 1968, pp. 1191-1200.

Lewis McAdory Branscomb

Astin's choice to be the sixth Director of the National Bureau of Standards was Lewis Branscomb. The potential in the man was grand, in Astin's view. Branscomb was barely 42 years old, a product of Asheville, North Carolina; Duke University (A. B. summa cum laude, 1945); the U.S. Naval Reserve; and Harvard University (M. A. 1947 and Ph. D. in physics, 1949). He had been invited to join the staff of the Bureau by Director Edward Condon in 1951, and it had soon become clear that this man would make a mark.

Lewis M. Branscomb, sixth director of the National Bureau of Standards.

Branscomb's Negative Ion Photodetachment Experiments

Branscomb badly wanted in 1951 to perform a particular experiment involving negative hydrogen ions. He felt that the experiment was important for several reasons, one of which related to astrophysics. The sun's light, it had been known for years, really did not satisfy Planck's theory of thermal radiation from a hot body in the way that radiation from a laboratory blackbody did. The spectral distribution of the sun's radiation was "wrong"—that is, the radiant flux per unit wavelength measured over all the radiating wavelengths yielded a curve that differed from Planck's classic spectral distribution law. This deviation had been ascribed to absorption of visible and near-infrared radiation in the sun's photosphere by negative hydrogen ions, but laboratory evidence for this absorption was lacking. Branscomb wanted to look for photodetachment of electrons in negative hydrogen; he wanted to evaluate the cross-section for the process and study its wavelength dependence.

Unable to gather the resources for this work at Harvard, Branscomb took a train ride from Boston to Washington to see about the prospects at NBS. He met with several scientists at the Bureau, including Director Edward Condon. When Condon met Branscomb and heard of his plans, he encouraged the young physicist to try to assemble his experiment at the Bureau. Atomic physics was Condon's favorite field of science, and Branscomb seemed to Condon to be just the sort of scientific go-getter, trained in the new quantum physics, who could help rejuvenate the NBS scientific staff.

Branscomb was happy to contemplate work at NBS where long-term experiments, sometimes involving large collections of equipment and manpower, were known to be the norm rather than the exception. Robert D. Huntoon, Chief of the Bureau's Atomic and Radiation Physics Division, offered Branscomb a job, along with the opportunity to undertake his experiment. Branscomb also found at the Bureau the leeway needed to bring on board Stephen J. Smith—like himself a new Ph. D. from Harvard—and a succession of other bright, young scientists to help with the project.

The experiment that Branscomb designed was successful. He and two colleagues, Wade L. Fite and Stephen Smith, published in the journal *Physical Review* details of the apparatus and the first results.[12] The experiment confirmed the theoretical view that the photodetachment reaction could be significant in the solar spectrum. As Branscomb and Smith put it:

> The departure of the continuous solar spectrum, between 0.6 μm and 1. 6 μm, from the Planck blackbody curve were first ascribed by R. Wildt to the continuous absorption of the H^- ions in the solar photosphere. The electron affinity of H^- is about 0.75 eV and the ion has only one bound state. Hence the absorption of visible and near-infrared radiation leads to photodetachment according to the equation
>
> $$H^- + h\nu = H + e^-.$$
>
> The calculation of the cross-section for this process has been carefully performed by S. Chandrasekhar. Until the work of Branscomb, Fite, and Smith, negative-ion photodetachment had not been observed in the laboratory.

[12] L. M. Branscomb and Wade L. Fite, "Photodetachment of the hydrogen negative ion," *Physical Review* **93**, No. 3, p. 651 (1954); L. M. Branscomb and Stephen J. Smith, "Experimental Cross Section for Photodetachment of Electrons from H^- and D^-," *Physical Review* **98**, No. 4, p. 1028 (1955); Oral History, L. M. Branscomb, July 11, 1988.

The apparatus put together by Branscomb, Fite and Smith had yielded results in good agreement with the theoretical prediction for the sun's atmosphere. As a result of their work, a wholly new experimental area in ion photodetachment suddenly became available, allowing Branscomb and his colleagues at NBS to study ions that were significant in the earth's upper atmosphere as well as in the atmospheres of stars. They expanded on the hydrogen work to include the study of negative atomic and molecular oxygen ions, O^- and O_2^-, the evaluation of electron affinities, and the relation of these reactions to the earth's ionosphere.[13]

For nearly two decades this area of physics was the domain of Branscomb and a growing atomic-physics research group at NBS. Eventually the series of projects would lead to the founding of the Joint Institute for Laboratory Astrophysics in conjunction with colleagues at the University of Colorado.

Branscomb surely had a flair for physics. And he found the Bureau to be a very congenial place to practice science. He said:

> I very quickly appreciated that, first of all, the Bureau is the unique place in all the world to do very hard, very accurate, as well as very precise measurements . . . Therefore, if you wanted to push the fundamental standards by the most innovative means and make radical progress in basic standards of measurement, the way to do it was to hire outstanding scientists who wanted to do a piece of pure science that was so hard to do that they had to invent a new basic standard of measurement in order to do it.[14]

In 1954 Branscomb was named Acting Chief of the Bureau's Atomic Physics Section. Peter Bender joined the group in 1956, and Earl Beaty and theorist Sydney Geltman (hired from the Applied Physics Laboratory of Johns Hopkins University in Silver Spring, Maryland) came in 1957.

The Joint Institute for Laboratory Astrophysics

Besides his intense interest in physics, Branscomb had another flair, too—one which eventually would take him right out of the laboratory. This gift was ability in scientific administration. Branscomb was deeply perceptive about projects and programs in technical fields, and he had strong ideas about how to accomplish them. These qualities were combined in his nature with a very persuasive personality to make him the center of a whirlwind of activity.

Branscomb's interest in scientific administration surfaced during 1957-58, while he fulfilled a Rockefeller Public Service Fellowship at the University College in London. He said:

> The Rockefeller Public Service Award was the most wonderful thing that ever happened to me, except for the (Harvard) Society of Fellows. It was a full-year sabbatical. It paid for you and your family to go wherever you were going

[13] Lewis M. Branscomb, "A Review of Photodetachment and Related Negative Ion Processes Relevant to Aeronomy," *Annales de Geophysique* **20**, pp. 88-105 (1964).

[14] L. M. Branscomb, Oral History, July 11, 1988.

> overseas. It had provision for incidental expenses. I went off to University College in London, where Sir Harry Massey was, who had written the only book on negative ions that existed. I went for the purpose of greatly expanding and co-authoring the book with him. That never happened. The reason was that I divided all the problems of negative ions up into chapters and each chapter grew and grew as I discovered how little people knew. What was to be a book ended up as 10 research careers in all these areas. I met another Bureau employee whom I had known very briefly at Harvard as a graduate student and that was Dick (Richard N.) Thomas. Thomas was at the Boulder Lab, one of two astrophysicists hired by the NBS Boulder Labs, who had a connection with the High Altitude Observatory . . . We began to hatch out the idea that there really ought to be a proper group of atomic physicists interested in astrophysical applications, and astrophysicists who really wanted to do the astrophysics not in the classical way but in the quantum mechanical way . . . We cooked up the idea, the two of us, that if somehow we could take the atomic physics group in (NBS) Washington and these two astrophysicists—John Jeffries was the other one—in Boulder and marry them up, we would leave the Bureau and we would go somewhere, and we would do this great thing.[15]

This "great thing" became a project which was to occupy the attention of Branscomb for a decade.

Director Astin, approached by Branscomb with the idea that one of the Bureau's most productive research groups wanted to leave in order to further its research goals, suggested that the work could be done as a part of NBS. Together, they explored the possibilities.

Meanwhile, late in 1959, the NBS Atomic and Radiation Physics Division was separated into two divisions—the Radiation Physics Division, under the leadership of Lauriston S. Taylor, and the Atomic Physics Division, with Lewis Branscomb as its chief.

The discussions involving Branscomb and Astin about a new research organization—the "great thing" of Branscomb's Rockefeller sabbatical—began to focus on the nature and purpose of such an entity. In its Annual Reports for the period 1960-1962 the Bureau described plans for a new project to complement national programs in space science, plasma physics, and atmospheric research.[16] In 1960 the Space Sciences Board of the National Academy of Sciences heard the Bureau plans and recommended to the Department of Commerce that a coordinated program be undertaken for the study of the basic physics of atoms and molecules in terrestrial, planetary, and stellar atmospheres.

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[15] Ibid.

[16] *Miscellaneous Publication 237*, December 1960, p. 10; *Miscellaneous Publication 242*, December 1961, p. 6; *Miscellaneous Publication 246*, December 1962, p. 7. In the last-named reference, NBS announced the establishment of the Joint Institute for Laboratory Astrophysics in collaboration with the University of Colorado.

The proposal for a program that would connect NBS with a university in the study of laboratory astrophysics attracted considerable attention in the scientific community, where the lack of trained astrophysicists was known to be a serious one; the reception accorded the concept was entirely favorable in that sector. In the Department of Commerce, however, many questions were raised—about the propriety of participation by NBS staff members in the everyday teaching activities of a university, for one thing, not to mention the difficulty of giving the government employees appropriate compensation for teaching. The department also was concerned about the suitability of sharing rented space between staff members of a university and Bureau employees. Nor did the department feel comfortable about the creation of a DoC entity expressly devoted to basic scientific research, ordinarily the province of the National Science Foundation.

These administrative questions involved NBS Director Astin in detailed discussions with several officials in the Department of Commerce. Memoranda traveled the circuit, carrying ideas and concerns back and forth. Astin and his legal minds pointed out to the DoC and *their* legal minds the similarity of the proposed venture to the Smithsonian Astrophysical Observatory, where Civil Service employees held joint academic appointments at Harvard University, and to the NASA Institute for Space Sciences, where Robert Jastrow, chief of the NASA theoretical division, simultaneously held the position of Professor Adjoint in the Department of Geology at Columbia University. Also discussed was the idea that teaching would help mightily to provide a stimulating research atmosphere and to disseminate the latest information in a rapidly changing field that held intense interest for important portions of the U.S. government.

Eventually the natural nervousness of the Commerce Department in contemplating a new approach to the way NBS wanted to do its work was overcome. A major part in calming the department's fears was played by the many proponents of the program in the upper circles of the federal science establishment—Branscomb and Astin had prepared their case carefully and could easily establish a need for the new undertaking.

Desirous of placing the NBS astrophysical project in the fertile environment of a university with a strong graduate program in astronomy, the Bureau group held preliminary discussions with Harvard, the University of California at San Diego, the University of Arizona and the University of Colorado. The last-named school had several advantages—a High-Altitude Observatory and a Laboratory for Atmospheric and Space Physics within the University framework, plus the nearby National Center for Atmospheric Research.[17]

Many details of the new program had to be attended to, since the prospective entity was a most uncommon species for NBS.

At last, a Joint Institute for Laboratory Astrophysics (JILA) was created through a Memorandum of Understanding between the NBS and the University of Colorado. The Memorandum was announced on April 13, 1962, by the two organizations.

[17] Lewis Branscomb, Oral History, July 12, 1988.

The general features of JILA as planned included the following components:

1. Staff (intended eventually to number about 25).

- NBS employees (initially, eight staff members from the NBS Atomic Physics Division and two—both theoretical astrophysicists—from the NBS/Boulder laboratories) who would be assigned to JILA to work and who would hold adjunct professorships at UC.
- Faculty members in astrophysics and space physics from UC.
- Faculty members in the aerodynamics department of UC.
- Up to ten visiting members—usually on one-year appointments—working on problems of their choice while on leave from their own institutions.

2. Scientific objectives.

- Research in basic atomic physics.
- Research on the cooperative behavior of gaseous species important to astrophysics.
- Applications of stellar astrophysics.

3. Academic objectives.

- Teaching in the UC undergraduate and graduate programs.
- Providing seminars and personal instruction for students.
- Increasing the number of scientists trained in the astrophysics area.

As of April 1962 Lewis Branscomb became the first JILA Chairman. He and a small band of carefully selected colleagues soon left Washington for a bright new future near the Rocky Mountains. The group included John L. Hall (Ph.D., Carnegie Institute of Technology, 1961, interested in laser research); Stephen J. Smith (Ph.D., Harvard University, 1954, specialist on photodetachment of negative ions); Gordon H. Dunn (Ph.D., University of Washington, 1961, whose interest focused on atomic collisions); George Chamberlain (Ph.D., Yale University, 1961, working on atomic beams); Earl C. Beaty (Ph.D., Washington University, 1956, whose fields were ionic mobilities and atomic clocks); Lee J. Kieffer (Ph.D., St. Louis University, 1958, studying spins and moments in radioactive nuclei and electron-atom scattering); Sydney Geltman (Ph.D., Yale University, 1952, expert on the theory of ionic mobilities, atomic scattering, ionization and photodetachment); and Peter Bender (Ph.D., Princeton University, 1956, interested in atomic clocks and atomic resonance phenomena).[18, 19]

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[18] See p. 8 in *The Bureau Drawer*, Vol. 3, No. 9, May-June 1962.

[19] Gordon Dunn, Lee Kieffer, and Stephen Smith shared the Department of Commerce Gold Medal Award in 1970 for their studies of atomic collisions.

The first participants in the Joint Institute for Laboratory Astrophysics from NBS were, from left to right, Earl C. Beaty, Steven J. Smith, Gordon H. Dunn, Lewis Branscomb, Lee J. Kieffer, Peter Bender, John L. Hall, Sydney Geltman, George Chamberlain, and Carl Pelander.

From the perspective of NBS the group became Division 95, Laboratory Astrophysics, with residence in the Boulder, Colorado Armory Building. The Atomic Physics Division, by this time comprising seven sections, was left in the capable hands of Karl Kessler, a career atomic spectroscopist.

In the fall of 1966, the JILA building—a 10-story office tower, laboratory wing and auditorium shown in the accompanying photo—was completed and occupied, bringing to full fruition the plans laid a decade earlier by Branscomb and Thomas for this new "great thing."

As this narrative continues, we shall frequently recognize important contributions from the staff of JILA.

The Joint Institute for Laboratory Astrophysics Building on the campus of the University of Colorado in Boulder.

Branscomb's Outside Activities

By 1960, Branscomb had begun to play an increasingly active role in the scientific establishment beyond the confines of NBS. From 1960-65 he served on the Reaction Rate working group of the Defense Atomic Support Agency. In 1961, he also took on the chairmanship of the Division of Electron Physics of the American Physical Society and service on the Advisory Committee on Ballistic Missile Defense for the Advanced Research Projects Administration. Participation in such groups intensified as Branscomb's administrative talents became more widely known.

While Branscomb was chief of the Atomic Physics Division in 1961, he was awarded the Department of Commerce Gold Medal for Exceptional Service. The award was based upon "contributions to basic knowledge of atomic processes of stellar atmospheres, terrestrial ionosphere and interplanetary space." The medal was given principally to recognize the importance of his work on photodetachment of electrons from hydrogen ions.

In 1962, Branscomb was presented the Arthur S. Flemming Award, given to honor Federal employees under the age of 40 for unusually meritorious work.

From 1965-69, Branscomb served on the President's Science Advisory Committee (PSAC) as Chair of the Panel on Space and Technology. At that time, he was the only member of PSAC who was a working scientist at a Federal laboratory.

In 1966 Branscomb was appointed to the Board of Editors of the American Physical Society. In 1968 he began service as Editor of the Review of Modern Physics, supporting with his own efforts his belief in the value of the review literature both for scientific data and for science generally.

That same year he was given the Bureau's Samuel Wesley Stratton Award, which honors unusually significant research contributions to science or engineering in support of NBS objectives.

Branscomb Becomes NBS Director

Allen Astin had made very clear his desire to be succeeded as NBS Director by Lewis Branscomb. A methodical man, Astin had planned ahead for his retirement in 1969, when he would turn 65 years of age. John Kincaid, Assistant Secretary of Commerce for Science and Technology, wondered in a memorandum to his boss, Secretary Alexander Trowbridge, whether the best way to achieve an orderly transition at the Bureau might be for Astin to step aside prior to the 1968 national election so that Branscomb could be nominated and installed as Director without regard to whether the Republicans or the Democrats won the Presidential election.[20]

Two little problems stood in the way of this solution. Allen Astin was not interested in retiring from a position of "senior advisor," as Kincaid suggested in his memo; Astin would be the boss until the day he left government employment. Furthermore, Branscomb was not interested in being a party to an attempt to finesse the next national administration. He wrote:

> I think it is not useful to the Bureau of Standards for me to undertake a commitment at this time which might serve to tie the Secretary's hands should there be a change in administration or for any other reason.[21]

Branscomb was not even sure that he wanted to be NBS Director. In a conversation with Astin, Branscomb remarked that,[22] in fact, he did not want the Directorship—he wanted to stay at JILA. He felt that accepting an NBS administrative job above the level of Division Chief would bring to an end his active participation in science.

Yet, said Branscomb later, he could not dismiss Astin's request to consider the Directorship. Astin had been too helpful to him, in bringing JILA to life and in other ways. If Astin could make the nomination happen somehow, Branscomb would serve.

[20] Memo to Secretary Trowbridge from Assistant Secretary Kincaid, September 26, 1967. (DOC, Assistant Secretary for Science and Technology, Accession 40-72A-7166, Box 8, Folder Chron File (August-September 1967) JFK).

[21] Letter from Branscomb to Kincaid, January 27, 1968. Same accession data as Kincaid-Trowbridge memo.

[22] L. M. Branscomb, Oral History, July 12, 1988.

The issue of succession to the leadership of NBS became a very murky one indeed when the Presidential election votes were counted.

Republican candidate Richard Nixon and his running mate, Spiro Agnew, former Governor of Maryland, captured the Presidency in 1968 by winning 31.8 million votes to 31.3 million for the Hubert Humphrey-Edmund Muskie Democratic ticket and 9.9 million for the American Independent Party standard-bearers, George Wallace and Curtis LeMay. Despite their narrow popular plurality, Nixon and Agnew won 301 electoral votes of the 538 votes available.

Now there was a difficulty for the potential Branscomb nomination. Branscomb was a registered Democrat. More problematic was the fact that his wife Anne, a lawyer, had for some time been quite active in Colorado politics and in 1968 was a member of the Democratic National Committee. While the position of Director of NBS had never been a political job, the new administration might well go looking for a nominee who was less obviously a member of the defeated party.

During the early months of 1969, friends of Astin in Congress and elsewhere tried to convince the incoming administration that Branscomb was the best choice for the next Bureau Director, despite any little political flaws. The Republican establishment in Colorado was particularly hard to convince of this idea, because they already had permitted one Colorado Democrat to be appointed over their objections.[23]

It is rare in such cases that more than a trace of the pre-nominative process—telephone calls, memos, visits, cajoling, "horse trading"—would become available to historians. Branscomb certainly knew few of the details. He recalled that only later did he learn that one Peter Flanigan, friend of Richard Nixon and brother of the Colorado Republican State Committee Chairman, intervened on behalf of the Branscomb nomination. Whether that intervention tipped the scales in Branscomb's favor, whether Branscomb's brief service to the new administration as a scientific member of one of the new President's "transition teams" carried the day, or whether the newly appointed Secretary of Commerce, Maurice Stans, and other powerful members of the incoming administration simply agreed that Branscomb was a good choice for the job, the result was that Branscomb, one day in the early summer of 1969, was asked to meet with Secretary Stans at the Department of Commerce offices downtown.

Branscomb recalled that meeting with some pleasure. Secretary Stans said something like, I am told that you are a very good scientist and show great promise as Director of the Bureau of Standards and that it would be a mistake for me not to appoint you to that job. I am prepared to make the appointment. I don't know what all you do at NBS, but if you do it well, stay out of trouble, and agree not to interfere with my primary job, which is to help raise the money to get President Nixon re-elected in 1972, we'll get along just fine. Branscomb assured the Secretary that he could readily promise not to get involved at all in Republican fund-raising, and the nominating process was essentially complete.[24]

[23] L. M. Branscomb, Oral History, 12 July, 1988.

[24] L. M. Branscomb, Oral History, 12 July, 1988.

According to a special edition of the *NBS Standard* issued on June 23 1969:

> Secretary of Commerce Maurice H. Stans today (June 17, 1969) announced that the President has nominated Dr. Lewis M. Branscomb, 42, of Boulder, Colorado, as Director of the National Bureau of Standards.
>
> Secretary Stans said that Dr. Branscomb, an internationally known atomic physicist and a career Federal scientist-administrator, would assume his new duties on the retirement on August 31 of Director Allen V. Astin.

Astin was content. In the same edition of the *NBS Standard,* he wrote a note to the Bureau staff:

> I am sure that you will be as pleased as I am to know that Dr. Lewis M. Branscomb is being nominated.[25]

Branscomb was given an early opportunity to show what grasp he might have of Bureau policies and programs. On July 31, 1969, he was interviewed by the Committee on Commerce of the U.S. Senate, Warren Magnuson presiding. Two aspects of the record of that nomination hearing are interesting. First, the hearing was short and therefore presumably non-controversial in the eyes of the Committee. Second, Branscomb was asked to defend the budget request for the Bureau's National Standard Reference Data program, as well as to explain why he—as an employee of NBS—should have been performing basic research in the field of astrophysics. His response to the first request showed considerable familiarity with the NSRD program and an intense support for its goals. His response to the second request sounded a theme that was to become Branscomb's guiding principle during his short tenure as Director of NBS:

> I believe the Bureau has an important job beyond commerce to insure that it provides, if you like, the infrastructure of the Nation's science and technology. Without a vital and high-quality, reliable measurement capability the country's science and technology cannot be effective in application.

The Committee was quickly satisfied that Branscomb's nomination should be confirmed. The Senate ratified the nomination on August 7th, with three weeks to spare before Astin's retirement.

The prospects for NBS looked bright indeed—one of its most exciting young scientists had been appointed its sixth director. With an eloquent spokesman—one well-connected to the Washington scientific establishment—to lead the way, could there be any but good times ahead for the Bureau?

[25] A. V. Astin, The *NBS Standard* Special Edition, June 23, 1969, p. 2.

Taking Charge

Once he became Bureau director, Branscomb had work to do. Although he was very familiar with the major policies and programs of the Bureau, there were many people—both technical and administrative—that he didn't know at all. One need only refer to the previous chapter of this book to realize that considerable effort would be needed even to approach a comprehensive acquaintance with the Bureau staff and its diverse activities.

The senior management team that Allen Astin had left to Branscomb was composed in the main of "old hands." Lawrence Kushner, Ernest Ambler, John Hoffman, Carl Muehlhause, Howard Sorrows, Robert Walleigh, Bascom Birmingham, Edward Brady, and Robert Ferguson had served NBS in aggregate for more than a century. These men, Branscomb knew and they knew him; their immediate subordinates he did not know well.

Branscomb recalled that he spent his first day on the job visiting the Institute and Center Directors—Ambler in Basic Standards, Hoffman in Materials Research, Sorrows in Applied Technology and Muehlhause in Radiation Research—and their principal managers.[26] This was to be a series of get-acquainted meetings, an exercise in "team-building." Mostly, the day passed quickly, pleasantly and without incident. There was one exception, however. One of the managers noted that he hoped that Branscomb would "... stay out of my hair, and we'll get along fine." Branscomb, astounded at the man's unwillingness to meet the new director halfway, quickly reassigned him to a non-management position.

From his new vantage point, Branscomb reviewed the scientific literature for the journal *Measurements and Data.*[27] He called for a clearer separation of scientific publications into categories such as news, conference proceedings, archives, and critical reviews, with emphasis on specifying the quality of particular measurements and thus their subsequent value as components of theoretical or engineering design. These ideas, long on Branscomb's mind, had come to sharper focus over the past two years during his service as Editor of the journal *Reviews of Modern Physics.*

Some five weeks after taking office, the new director addressed the NBS staff for the first time. In his remarks, Branscomb showed his confidence that Allen Astin had left the Bureau healthy, and his own intention that the course should not waver. He urged Bureau employees to continue the dedication to accuracy and integrity fostered by Astin, to continually be conscious of the national welfare in their work, to look for ways to enhance the nation's economic and social progress through measurement science, and to observe their responsibilities as the Nation's measurement laboratory. He took note of the 1967 Flammable Fabrics Act, the Metric System Study, the bottleneck in national building codes, and the fundamental importance of the National Standard Reference Data System. In each of these applied-science projects, he ascribed a significant role for new achievements in measurement, the Bureau's strength.

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[26] L. M. Branscomb, Oral History, 12 July, 1988.

[27] L. M. Branscomb, *Truth in packaging of scientific information*, Measurements & Data 3, No. 5, 104-105 (1969).

In November of 1969, Lee A. DuBridge, the Science Advisor to the President, released for publication a report of the Space Science and Technology Panel of the President's Science Advisory Committee; the panel was chaired by Branscomb. Entitled *The Biomedical Foundations of Manned Space Flight,* the report was prepared by a working group on Space Medicine. It contained several recommendations intended to optimize the benefits of manned space flight, given the tension between the high cost of manned flight and the limited resources available for the project. Publication of that report marked the end of Branscomb's service on PSAC.

The changes made by Branscomb in his 1972 budget request had more immediate impact upon Congress than they did on the Bureau staff, perhaps because he could take his time in creating the structures that would give life to his vision of NBS. Astin had left behind an organization managed mostly by experienced leaders who knew the Bureau and its clients from long personal association. They were themselves scientists with solid records of accomplishment, and they had faith in the quality of their service to America. Nearly a year would pass before Branscomb's views on organizing the Bureau around consumer issues would be assimilated within NBS.

Establishment of NBS Executive Board

One of Branscomb's first acts as director was to establish an Executive Board "to assist me in managing Bureau affairs." He envisioned a group that would meet with him in executive session for decision-making discussions, and in regular sessions for program planning. Initial assignments to the board included:

- Lawrence Kushner, Deputy Director, NBS.
- Edward Brady, Associate Director for Information Programs.
- Robert Walleigh, Associate Director for Administration.
- Ernest Ambler, Director, Institute for Basic Standards.
- John Hoffman, Director, Institute for Materials Research.
- Howard Sorrows, Acting Director, Institute for Applied Technology.
- Carl Muehlhause, Director, Center for Radiation Research.
- Herbert Grosch, Director, Center for Computer Sciences and Technology.

Meeting with the board during regular sessions would be:

- Robert Ferguson, Coordinator for Program Planning.
- Robert Huntoon, Coordinator for Policy Planning.
- Bascom Birmingham, Deputy Director for Boulder, IBS.[28]

Establishment of NBS Program Office

One of Branscomb's first appointments changed NBS markedly. Branscomb created the position of Associate Director of NBS for Programs (ADP). He placed Howard E. Sorrows, Acting Director of the Institute for Applied Technology, in command and gave him the assignment of establishing "an office responsible for the analysis,

[28] NBS Admin, Bull. 69-59, September 2, 1969: "Executive Board Established."

planning, budgeting, documentation, and communication of programs at the Bureau level."[29] Robert E. Ferguson, Special Assistant to the Director for Program Planning, was assigned to the office as well. Malcolm W. Jensen was assigned to the position of Acting Director of IAT to replace Sorrows.

Sorrows was an excellent choice for program director. He had plenty of experience with scientific work and with the Bureau. NBS had provided his first scientific position—with the NBS Electricity Division in 1941. By 1950, he was head of the ultra-high-frequency standards group in the Central Radio Propagation Laboratory. He then left NBS to take sequential positions at the Naval Ordnance Laboratory, at the Office of Naval Research, and at the Navy Bureau of Ordnance. But perhaps his most useful preparation for organizing an NBS program office was his experience from 1959-63 at Texas Instruments, Inc., where he initiated and managed a department for technical intelligence, long-range planning, and new product development.

Sorrows knew well the need of technical groups to understand their products, their customers, and their organizational goals.[30] This approach was just the one that Branscomb wanted—a unit to bundle disparate projects in disparate divisions of the Bureau into a coherent attack on "national needs" that could trigger a shower of dollars from Congress, and, at the same time, encourage the divisions to shed provincial perceptions regarding their own programs.

Within 6 weeks, Sorrows had fleshed out the ADP role sufficiently that Branscomb was able to describe it for Larry A. Jobe, Assistant Secretary of Commerce for Administration:

> The Office of the Associate Director for Programs performs the functions of policy development and program analysis, program promotion, and financial interpretation: the Office sponsors and coordinates the performance of issue and impact studies; relates Bureau programs to national needs; generates planning formats and develops information on NBS program plans and status for internal and external audiences; administers advisory panels; defines alternatives for the allocation of resources and advises Bureau management on their implications; and directs the formulation of the budget.[31]

The Program Office quickly became a force at NBS. Young scientists—"program analysts"—soon found a tour of duty there to be physically exhausting, but ultimately rewarding in terms of advancement to managerial positions. Some of the old-line scientists soon found young gate-keepers (paid with money that could have been used for metrological or other technical projects!) standing in the way of needed funds and personnel slots and demanding justifications in terms of product marketability. Occasionally they seemed to discount or to disregard entirely scientific merit in making

[29] NBS Admin. Bull. 70-21, April 16, 1970.

[30] Bio file, Howard Sorrows.

[31] Memo, LMB to Larry Jobe, Asst Sec for Admin: "Revision of Department Organization Order 30-2B," May 28, 1970. RHA, RG 167, Director's Office, Box 389, Folder Chrono May 1-31, 1970.

funding recommendations. Adversarial relationships, based on need for resources—funds, people, or equipment—developed between scientific groups that had been natural colleagues. On the other hand, ties to the Nation's technical life became closer and clearer than they ever had been before the creation of the Program Office. Times at NBS were changing.

Gradually, the trend toward problem-oriented organizational units at NBS would become a flood. In time, the old-line metrological-standards units would wonder whether they still had a place at the Bureau.

In July 1970, Branscomb assigned to James R. Wright, Chief of the Building Research Division, the additional responsibility of cooperating with the Program Office to coordinate NBS efforts with the Department of Housing and Urban Development. The relatively new department—formed in 1965—worked closely with the Bureau on many housing-related projects. Wright's new duty was to provide a continuing point of contact between the organizations, although no management function was involved.[32]

Towards the end of 1970, Robert Ferguson, Sorrows' Scientific Assistant, was given the responsibility of coordinating all NBS work on the Water Pollution Control and Abatement Program.[33] Ferguson also was directed to monitor all environmental programs other than the Measures for Air Quality, which was administered by James McNesby.

By 1974,[34] one or another of Sorrows' program analysts was assigned to each of the Bureau's new budgetary program areas:

- Scientific and Technical Measurements.
- Use of Science and Technology.
- Equity in Trade.
- Public Safety.
- Technical Information.
- Central Technical Support.
- Experimental Technology Incentives Program, a new category.

The analysts so involved in June 1974, included Martin J. Cooper, Thomas Dillon, Cary Gravatt, Sanford B. Newman, Stanley Rasberry, and Norman F. Somes.

Measures for Air Quality

Early in 1970, Branscomb became aware that a small group of chemists and physicists shared an interest in scientific work that could be used to evaluate or mitigate air-pollution problems. James R. McNesby, Chief of the Physical Chemistry Division, had created an informal study group to interact with like-minded scientists, mostly within the U.S. government.

This effort struck Branscomb as just the kind of consumer-oriented project that he envisioned for NBS. Immediately, he asked McNesby to organize a program-management office for airpollution studies. The new office was called Measures for

[32] NBS Admin. Bull. 70-49, July 23, 1970.

[33] NBS Admin. Bull. 70-49, July 23, 1970.

[34] NBS Admin. Bull. 74-44, June 25, 1974.

Air Quality.[35] McNesby would report to John Hoffman, Director of the Institute for Materials Research. Radford Byerly, Jr., one of Howard Sorrows' first Program Analysts, was designated deputy to McNesby.

Milton Scheer was detailed to replace McNesby as chief of the Physical Chemistry Division.

As an NBS entity, Measures for Air Quality (MAQ) bore considerable similarity to the Office of Standard Reference Data (OSRD) and the Office of Standard Reference Materials (OSRM). There was no re-assignment of participants in the program; collaborating scientists would remain with their technical divisions, where they could maintain their usual mix of professional activities.[36] At that time, these three programs—MAQ, OSRD, and OSRM—made up the entirety of the "matrix management" activities at the Bureau that were described in Chapter 1.

A study of Bureau projects by the MAQ scientists turned up even more work, in several different divisions, that could be applied to air pollution measurements or abatement. One of these efforts followed a 1972 meeting sponsored by NBS and the Environmental Protection Agency; its purpose was to pinpoint standard gases needed to monitor pollution from automobile exhaust. As a result of the discussion, the Bureau began to prepare four gas mixtures—propane in air, carbon dioxide in nitrogen, carbon monoxide in nitrogen, and nitric oxide in nitrogen. Soon, these reference gases were part of the Standard Reference Materials program.

As these projects developed, McNesby was given access to funds to stimulate work in each area. Gradually, other government agencies assisted with funding. McNesby and his tiny staff coordinated NBS efforts with those of other organizations interested in the problem of air pollution and facilitated attendance at conferences and publication of papers. Eventually the program produced nitric oxide and sulfur dioxide monitors for use in field stations.

Change in the Center for Radiation Research

Concerned that the component divisions of the Center for Radiation Research were not flourishing in their current structure,[37] Branscomb revised that structure considerably in September 1970.[38] In one move, the Reactor Radiation Division was taken out of the Center and placed in the Institute for Materials Research under John Hoffman; Branscomb opined that, in this move, the RRD would "benefit from the broad scientific and technical base and the considerable managerial strength of [the IMR]."

James E. Leiss, former chief of the Linac Radiation Division, was named Acting Director of the Center. The Center itself was shifted to the Institute for Basic Standards, under Ernest Ambler.

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35 NBS Admin. Bull. 70-42, June 30, 1970.

36 "Measures For Air Quality," NBS Technical News Bulletin, Vol. 57, No. 1, January 1973, pp. 10-13.

37 Letter to members of the CRR Advisory Panel from LMB, September 1, 1970. RHA, RG 167, Director's Office, Box 389, Folder September 1-30, 1970.

38 NBS Admin. Bull. 70-57, September 1, 1970.

In 1972, during a meeting jointly sponsored by the Environmental Protection Agency and NBS, it was decided that Standard Reference Materials (SRMs) were needed to monitor compliance with auto emission laws. As a result, NBS developed four gas-mixture SRMs. Ryna B. Marinenko prepared these primary reference standards.

Carl Muehlhause, Director of CRR, was re-assigned to serve on Branscomb's staff. These changes reduced by one the number of managers that reported directly to Branscomb and, he hoped, strengthened both the Reactor Research Division and the Center for Radiation Research.

Clearinghouse for Federal Scientific and Technical Information Transferred to the National Technical Information Service

A Department of Commerce Organization Order mandated the transfer of the Clearinghouse for Federal Scientific and Technical Information to the National

Technical Information Service on September 2, 1970.[39] In early April of that year, Branscomb and Edward Brady, NBS Associate Director for Information Programs, responded to a request from Myron Tribus, Assistant Secretary of Commerce for Science and Technology, for information on the activities of the Clearinghouse.

At issue was the variety of publications prepared and circulated by the Clearinghouse, as well as its methods of distribution. Department officials were disturbed that it was necessary to subsidize the operations of the clearinghouse despite the fact that its publications were sold, not given free of charge, to the public.[40]

Management of the NBS Instrument Shop

Administrative management of the instrument shop, the central NBS facility for the manufacture of specialized apparatus used in research projects in all the technical divisions, was changed in August 1970 from the control of the Director of the Institute for Applied Technology to that of the Associate Director for Administration.[41] Branscomb hoped, by this move, to make the operation and financial support of the shops more equitable for the many divisions that made use of shops resources.

Ruth M. Davis, A New Leader for the Center for Computer Science and Technology

One of Lewis Branscomb's early priorities was to obtain new leadership for the Center For Computer Science and Technology to improve its effectiveness in cooperating with its many colleagues in government and industry. For this post, Branscomb was able to recruit Ruth M. Davis, an applied mathematician trained at the University of Maryland. Davis was the first woman to head a technical organization at the level of division or higher within the Bureau.

Davis was by all accounts a "whiz kid," having accomplished many feats in computer science in the space of perhaps 15 years. She taught the first advanced computer-programming and numerical-analysis courses ever given at the University of Maryland. She developed the first computer programs for nuclear reactor design while working with the U.S. Department of the Navy. And she improved the Navy's military command and control systems by preparing automated display-centered information systems.

From 1967 until coming to NBS in October 1970, Davis worked for the National Library of Medicine, part of the National Institutes of Health, where she was Director of the Lister Hill National Center for Biomedical Communications.[42]

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[39] NBS Admin. Bull. 70-59, September 3, 1970.

[40] Letter, LMB to Myron Tribus, April 8, 1970, RHA, RG 167, Director's Office, Box 389, Folder Chrono April 1-30, 1970. Letter, Edward Brady to Myron Tribus, April 17, 1970, RHA, RG 167, Director's Office, Box 389, Folder Chrono April 1-30, 1970. Letter, LMB to Myron Tribus, May 26, 1970, RHA, RG 167, Director's Office, Box 389, Folder Chrono May 1-31, 1970.

[41] NBS Admin. Bull. 70-54, August 12, 1970.

[42] NBS Admin. Bull. 70-69, "Dr. Ruth M. Davis Named Director, Center for Computer Science and Technology," November 4, 1970. See also *NBS TNB* December 1970, p. 282.

Davis continued her winning ways at the Bureau. In 1972, she was presented the Federal Woman of the Year Award,[43] the Association for Systems Management Systems Professional of the Year award, and the Department of Commerce Gold Medal Award. In 1973, she received the Rockefeller Public Service Award, earned by Astin and Branscomb a decade or more earlier. In 1974, Davis was elected to membership in the National Academy of Public Administration.

In 1977, Davis resigned her position at NBS to accept the post of Deputy Under Secretary of Defense for Research and Engineering. She left behind a seven-year tenure as director of the CCST that was marked by creative leadership.

Willenbrock Recruited to Head IAT

When Howard Sorrows left the Institute for Applied Technology to create the NBS Program Office, Malcolm Jensen—former Manager of Engineering Standards—was appointed Acting Director of IAT. A nation-wide search for a permanent director ended with the appointment of F. Karl Willenbrock, a Harvard-trained physicist, in November 1970.[44]

Willenbrock was Provost and professor of engineering and applied science at the State University of New York prior to coming to NBS. He was especially active in the Institute of Electrical and Electronics Engineers (IEEE), serving as its President in 1969. He also was a member of several government panels, and he represented the United States during the Second World Congress of the World Federation of Engineering Organizations. Willenbrock was at that time a member of the Information Council of the National Science Foundation. In 1976, he would leave his post as Director, IAT, to accept an engineering professorship at Southern Methodist University.

Although Willenbrock's tenure at NBS was not a long one, he left a lasting legacy—largely through his recruitment of John W. Lyons, Jack E. Snell, and Richard N. Wright, all future leaders at the Bureau.

Equal Employment Opportunity for Minorities and Women

We mentioned in Chapter 1 that Allen Astin helped stimulate passage of a Public Accommodations Ordinance in Montgomery County, Maryland, soon after NBS moved its main laboratory facility to Gaithersburg. Astin also established an Equal Employment Opportunity committee for the Bureau, to handle discrimination grievances and to combat discrimination in NBS recruiting and employment. Initially, those programs focused on the problems of African-Americans, who were victims of active racial segregation in the United States well after the Bureau passed its half-century mark. Housing, public facilities, and employment were still areas of concern for blacks in the 1960s.

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[43] "Dr. Davis Wins Federal Woman's Award," *NBS Standard,* Vol XVII, No. 3, April 1972, p. 1.

[44] NBS Admin. Bull. 70-72, "Dr. F. Karl Willenbrock Named Director, IAT," December 2, 1970. See also *NBS TNB* December 1970, p. 282.

Karl F. Willenbrock was director of the NBS Institute for Applied Technology from 1970 to 1976.

In December 1969, President Nixon strengthened the Executive Branch position on equal employment by issuing a new Executive Order urging, among other actions:

> Special efforts must be made to assure that opportunities in the Federal Government at the professional levels are made known to men and women of all races, religions, and ethnic backgrounds.[45]

By 1970 NBS had an active EEO effort. A nine-member EEO Committee with access to upper-level Bureau managers, an affirmative action plan, and grievance procedures combined to substantially improve the lot of black employees. Branscomb created the post of EEO Counselor to facilitate the grievance process; Wiley A. Hall, Jr. was the first to occupy that post.

Esther Cassidy, a physicist in the Electricity Division, was appointed by Branscomb in March 1970 as NBS representative to the Department of Commerce Federal Women's Committee. Her responsibilities extended across NBS in regard to equal employment opportunity for women.

As part of his program for employee development, Branscomb also created the post of Vocational Guidance Counselor. Roberta Hatwell, who filled the post, was charged with helping non-professional employees obtain vocational training in order to qualify for advancement at NBS.[46]

[45] "President Nixon Issues new EEO Order," *NBS Standard,* Vol XIV, No. 12, December 1969, p. 5.

[46] "NBS Has New Vocational Guidance Counselor," *NBS Standard,* Vol XV, No. 2, February, 1970, p. 3.

In May 1970, the "barbershop case" mentioned in Chapter 1 again made the news in Gaithersburg:

> Late in May a Howard County Circuit Court judge dismissed a $600,000 suit filed by a Gaithersburg barber against Avery Horton and James Walker, both chemists in the Bureau's Institute for Materials Research, and Bertram L. Keys, Jr., Executive Secretary for the Montgomery County Human Relations Commission. (The barber) had charged that the defendants had conspired to hurt his barbershop business by processing complaints of racial discrimination against him. Judge T. Hunt Mayfield ruled that (the barber) had failed to demonstrate anything but that the defendants were attempting to enforce Montgomery County's public accommodations ordinance, as they understood it.[47]

In June 1970, Horton received the first EEO award ever given by the Bureau. The award was given by Director Lewis Branscomb during an NBS staff meeting held specifically to discuss EEO policy. In his remarks, Branscomb called attention to Horton's personal commitment to eliminating racial discrimination.

Speaking in his role as master of ceremonies, Horton noted the painfully slow progress of the EEO movement at NBS and called for the development of standards against which progress could be measured. He also took note of the silence of the Bureau's EEO apparatus on the subject of discrimination against women:

> Before getting into this morning's discussion, I would like to relate to you a complaint that I received. No profile of a woman appeared in the (printed) program. Since by definition, Equal Employment Opportunity in government refers to minorities and women, I had no rebuttal. The committee is not insensitive to problems of women, but our determination of the problem of job inequities at the National Bureau of Standards concerns black employees, and our major corrective efforts have been in that direction.

In a separate talk given at the same meeting, Karl Bell, another EEO committee member, urged that a "climate of credibility" be created at NBS by employing more blacks at professional levels. Forget the "Super Black," he said, and concentrate on hiring the best available black employees and training them to realize their full professional potential. He emphasized that the promotion of black employees to management positions was an important yardstick for progress in EEO. Bell drew attention to statistics to bear out his concerns. NBS employed 473 blacks in 1965, but only 410 in 1970, following the move of the main campus to Gaithersburg. Most of the 410 still occupied the lowest-paid jobs; blacks comprised only 6 % of the NBS workforce in the professional ranks, with 19 technical divisions employing no blacks at all; and at the Section Chief level or above, only two blacks were to be found at NBS.[48]

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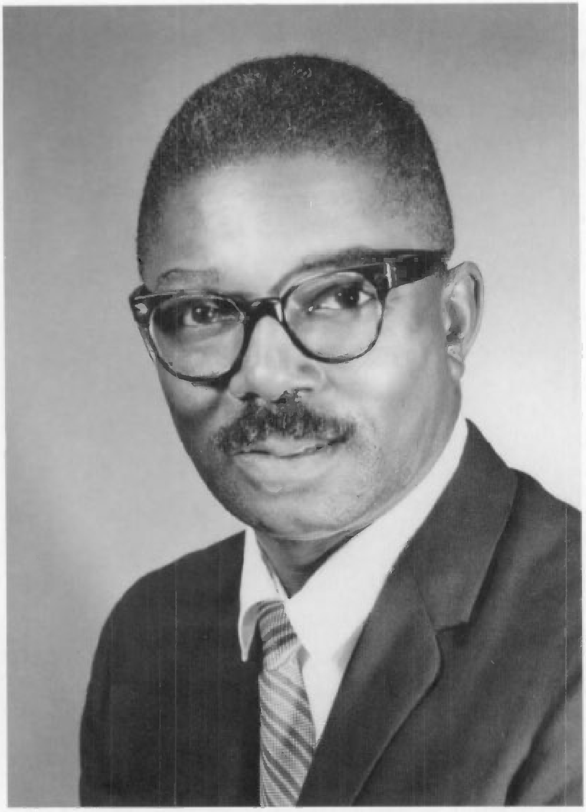
[47] "Barbershop Case News," The *NBS Standard,* Vol. XV, No. 5, May-June 1970, p. 5.

[48] "Special EEO Issue," *NBS Standard,* Vol XV, No. 6, July 1970.



Avery T. Horton, a physical chemist, studied crystal chemistry in the NBS Inorganic Materials Division. He also worked in the Bureau's Law Enforcement Standards Laboratory.

NBS had a better record with respect to women as professional employees. It is difficult to say how good it was, because gender was not recorded in Bureau statistics. But with respect to the "glass ceiling," which historically kept women from positions of leadership, the NBS record could not be praised: until Ruth Davis was appointed director of the Center for Computer Sciences and Technology in 1970, no woman led a technical division, and only one occupied a position as high as section chief in a technical division.

The paucity of women in scientific and technical management roles merits further comment. During this period, relatively few women were encouraged to seek careers in technical fields.[49] Fewer still were able to pursue such careers on a full-time, long-term basis, mainly because family obligations still rested disproportionately on women. Since higher-level managers typically selected new managers from the pool of career scientists with long experience and long-term prospects, only careful consideration

[49] Although the outright prejudice against women ascribed to the Bureau's first director by Cochrane (*Measures for Progress*, p. 54) was long gone by mid-century, the decade of the 1970s still featured contests for "Miss NBS."

and special effort by the higher-level managers could introduce "gender equality" to leadership positions at NBS. Nevertheless, the time for Bureau-wide action on behalf of women had come.

During August of 1970, the 50th anniversary of the Women's Right to Vote amendment (the 19th amendment to the U.S. Constitution, ratified August 18, 1920) was reached. Both the Commerce Department and NBS took notice of the anniversary. Director Branscomb met with a group of senior women staff members to discuss their special problems. The talk quickly focused on the availability of day-care facilities and the significance of child care for working women. Branscomb, reporting on the meeting in a memo to the NBS staff, noted the existence of the Bowman house—left standing for experimentation by the Building Research Division when NBS occupied its new Gaithersburg site—and its possible adaptation to yet another worthwhile purpose.[50]

The Bowman House, purchased from its former owners when NBS obtained the surrounding property for the Gaithersburg site, was used by the Building Research Division until it was converted into a day care center in 1983.

[50] Memo, LMB to all employees, "Equal Employment Opportunity for Women," September 2, 1970; RHA; RG 167; Director's Office; Box 389; Chron file.

Subsequent to use of the Bowman House for a study of the effectiveness of insulating older homes (see Sect. Energy Conservation, p. 557), the Bureau's Plant Division adapted it for use in the child-care program in cooperation with the Standards Committee for Women.[51] The first "crop" of children—sons and daughters of NBS staff members, ages 2 years to 5 years—was welcomed in September 1983. Besides providing a day-care option for working parents, the Bowman House staff offered learning activities for all the children under the guidance of a Board of Directors elected from the families making use of the facility.[52]

During May 1988, an open house was held at the Bowman House to celebrate the addition of a new wing. The addition allowed further expansion of the day-care program. As this history was completed, the building still housed pre-school children at play.

In 1988, Deputy Director Raymond Kammer joined young clients of the NIST Day Care Center in a ribbon-cutting ceremony for the center's new wing as Director Lori Allen and Board President Kathy Stang looked on.

The appointment of Ruth Davis and planning an NBS center for child care were two steps in the direction of providing equal employment opportunities for women.

[51] The author is indebted to DeForest Z. Rathbone, Jr., former Plant Division employee in charge of special projects, for details on the Bowman house renovation.

[52] Jennie Covahey, "NBS child care center opens in September," *Commerce People*, August 1983, p. 6.

The NBS Budget

Branscomb's first order of business as Director was to understand the people and programs of the Bureau and to represent them effectively in budget hearings before the Committee on Appropriations, House of Representatives, Subcommittee on Departments of State, Justice, and Commerce, The Judiciary, and Related Agencies, John J. Rooney, New York, Chairman.[53]

Branscomb was well aware that Congressman Rooney vigorously protected the public purse from attacks by profligate agency heads who sought government funds for purposes not authorized by law—indeed, Rooney was not overly fond of approving appropriations even for projects specifically authorized by the House Committee on Astronautics. Branscomb later recalled:

> When I was Director, John Rooney of Brooklyn chaired—maybe I should say owned—the Subcommittee on Appropriations for Commerce, State, and Justice. Preparing for testimony before John Rooney was an agonizing affair, though not quite so agonizing as the experience of testimony itself. He ate government officials for lunch.[54]

Congressman Rooney expressed outrage frequently during his hearings, and he denounced in clear terms the efforts of those misguided or malicious public servants who offended his sense of fiscal integrity. The casual reader of the committee record might well wonder that any of Rooney's targets stayed out of jail, let alone survived in office to run—in perhaps most cases—quite effective organizations.

Despite the lurking dangers, Branscomb may have smiled a tiny smile as he contemplated his inevitable encounters with the House Subcommittee on Appropriations for State, Justice and Commerce. He knew that the cards were stacked against him in several respects. The Department of Commerce was not the ideal home for a technical agency such as the Bureau. The Bureau's importance to the Nation had always been hard to express in common terms, let alone to quantify to hostile laymen. And, of course, the Subcommittee members had no particular need to be civil to the people whose budgets they could influence so drastically.

However, Branscomb had a few cards to play, too—and the game interested him.

With Astin having completed the defense of the 1970 budget on May 13, 1969, Branscomb had a little time to prepare for his first encounter with the Subcommittee. He used it well.

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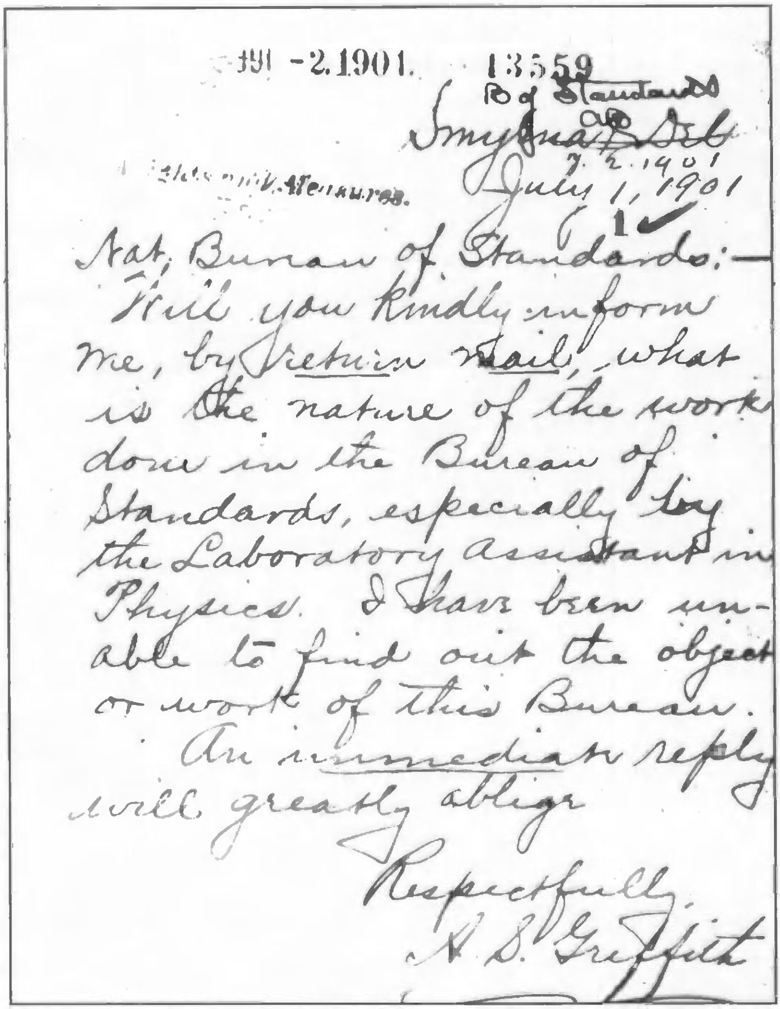
[53] The U. S. Senate Appropriations Committee had a similar subcommittee, chaired at that time by Sen. John L. McClellan. McClellan's subcommittee also had to approve the Bureau's appropriations. However, it was the House subcommittee that conducted hearings involving NBS testimony on its budget and initiated the appropriations process.

[54] Lewis M. Branscomb, "Historical Perspective: 1969-1973," in *NBS/NIST A Historical Perspective: A Symposium in Celebration of NIST's Ninetieth Anniversary, March 4, 1991, NIST Special Publication 825,* April 1992, p. 25.



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B of Standards

Smyrna Del

7. 2. 1901

July 1, 1901

Measures.

Nat. Bureau of Standards:—
Will you kindly inform me, by return mail, what is the nature of the work done in the Bureau of Standards, especially by the Laboratory assistant in Physics. I have been unable to find out the object or work of this Bureau.
An immediate reply will greatly oblige

Respectfully,
H. S. Griffith

NBS was established in 1901, in the midst of what historians have termed the Progressive Era (1890-1917). During this period, the American public increasingly turned to experts to help them solve complex problems arising in the new industrial society. At the same time, the lay public often harbored suspicion of this regime of technical experts, a situation that occasionally proved troublesome for NBS.

Fiscal 1971 Budget Hearings, March 1970

Branscomb's first budget presentation before Congress occurred on March 24, 1970. The NBS budget that he presented—the Fiscal 1971 edition—followed the format and emphasis of previous Astin budgets. "No substantial change in mission or objectives," despite the change in directors, read the introductory statement.[55] In his preparations, Branscomb had selected three programs—the metric study, flammable fabrics, and fire research and safety—for priority funding requests. These programs, he announced, were in great need of increased support.

Branscomb's other preparatory work had been to study the budget document almost to the point of memorization.[56] He was aware that Congressman Rooney often asked questions requiring precise knowledge of budget details and dollar figures; witnesses without ready responses could expect a rebuke. Thus, when Rooney asked for numbers, Branscomb—well prepared and well rehearsed—was able to supply many from memory and could find the others quickly. As usual, one of the numbers requested was the cost of the flagpole (in reality, the cost of the flagpole and its environs) in front of the Gaithersburg Administration building; without hesitation, Branscomb quoted the five-digit number.

The Bureau was allowed to ask for a $5 million increase for Fiscal 1971. Its total appropriation for the year, $44.2 million, reflected an increase of $3.6 million.

As Branscomb defended the Bureau's fiscal 1971 budget, he was already deep into plans for the following year's presentation. He felt that he needed to make much more clear the nature of the Bureau's contribution to the Nation's welfare.[57] He hankered for the kind of strategy used by the National Institutes of Health (NIH) and the Social Security Administration (SSA). The NIH named its institutes for medical problems (Cancer, Aging, Mental Health, etc), not for types of molecules that dominated the work in the various laboratories. The SSA, given its intensive use of computers for "number-crunching," could justifiably have named itself the "National Computer Center" but wisely chose to emphasize its area of public service.

How could Branscomb redefine Bureau programs to show their impact on the public? In the Institute for Basic Standards and in the Institute for Materials Research, its technical divisions had been organized to attack individual areas of measurement science for decades—Applied Mathematics, Electricity, Metrology, Mechanics, Heat, Atomic Physics, Radio Standards, Time and Frequency, Cryogenics, Analytical Chemistry, Polymers, Metallurgy, Inorganic Materials, Physical Chemistry. Still, there were exceptions. IBS and IMR contained consumer-oriented offices in Standard Reference Data and Standard Reference Materials, for example, and the Institute for Applied Technology incorporated many consumer-focused units—Engineering Standards Services, Weights and Measures, Invention and Innovation, Vechicle Systems, Product Evaluation, and Building Research.

Branscomb's solution to this challenge was to revise entirely the way in which NBS programs were presented to the House Appropriations subcommittee, and to introduce additional problem-oriented units to the NBS organization as the situation permitted.

[55] Hearings, House App. Subcommittee, March 24, 1970, p. 1021.

[56] Branscomb, Oral History, July 12, 1988.

[57] Branscomb, Oral History, July 12, 1988.

Working with his managers, with consultants, with the Department of Commerce, and with the Office of Management and Budget, Branscomb fleshed out a new budget-presentation scheme and prepared a "crosswalk" to correlate entries in previous budgets with items in the new one. After some months of effort, he sent his "homework" to Charles H. Alexander, Director of the Office of Budget and Program Analysis for the Department of Commerce, and requested permission to use it in the Fiscal 1972 budget.[58]

Fiscal 1972 Budget Hearings, April 1971

The new activity structure for the 1972 budget hearings was meant to convey a picture of NBS as a problem-solving, consumer-oriented institution:

- Providing the basis for the Nation's physical measurement system.
- Providing scientific and technological services for industry and government.
- Providing the technical basis for equity in trade.
- Providing technical services to promote public safety.
- Providing technical information services.
- Providing one-of-a-kind facilities for use by NBS and visiting scientists.

In presenting the new structure to the Bureau staff, Branscomb had been typically candid:

> There is nothing sacred about this program structure. Some of the elements are frankly experiments; we will have to see how they work out.[59]

It is interesting to notice that, by 1974, each of the operating units of the Bureau was assigned responsibility in one or another unit of Branscomb's program structure.[60]

Congressman Rooney, during the Fiscal 1972 hearings, appeared to surprise even himself by praising Branscomb's presentation of the new description:

> This is one of the better statements from the Department of Commerce . . . The statement is in language that represents the doctor's thoughts and he conveys those thoughts to the committee. I think this is very well written . . . However, don't rest on your laurels on that one, Doctor.[61]

The *repartee* during the April 1971 budget hearings would not be confused with the soft banter of old friends, but Branscomb had made a good start on his task of creating a new image for NBS. And, it should be noted, NBS received all the funding

[58] Memo, LMB to C. H. Alexander, Dir. , Office of Budget and Program Analysis, DoC: "Request for change in budget activity structure," RHA, RG 167, Director's Office, Box 389, folder Chrono, September 1-30 1970. Attachments, 12 pp.

[59] "From the Director's Office," *NBS Standard,* vol XV, No. 5 May-June 1970, p. 2.

[60] NBS Admin. Bull. 74-44, June 25, 1974.

[61] Hearings, House Committee on Appropriations, Subcommittee on Commerce, etc, 92nd Cong., 1st sess., April 20, 1971, pp. 1117-1140.

requested in the fiscal 1972 budget, increasing the Bureau's Congressional support level by some $5 million, to $49 million.[62]

Fiscal 1973 Budget Hearings, March 1972

The fiscal 1973 budget appropriation hearings, held on March 28, 1972, were remarkable for several reasons.

First of all, where was Congressman Rooney? Still the Chairman of the Subcommittee on Departments of State, Justice, and Commerce, the Judiciary, and Related Agencies of the House Committee on Appropriations of the 92nd Congress, Second Session, Congressman Rooney neither spoke nor sat during the hearings.

Rooney had been in charge 8 days earlier, when Peter G. Peterson, named Secretary of Commerce on January 27, 1972, by President Richard M. Nixon and confirmed by the U.S. Senate on February 21st, made his first appearance before Rooney's subcommittee. As part of his testimony on budget requests by the Department of Commerce, Peterson had suggested that a $14 million Experimental Technical Incentives Program be lodged within NBS. Rooney had been in fine form that day, asking:

> Do you think this is the right place in which to put this kind of trust?[63] You know, these great scientists out there were so wrong in figuring the cost of the building at Gaithersburg that I think it is the No. 1 white elephant in Government. Is there anything worse than that?

But on March 28, Mr. Rooney was missing, through illness or press of business elsewhere; no duel of words and numbers with the new Bureau Director would take place on that day. Rooney's position was filled by Congressman John M. Slack of West Virginia, a competent questioner and one not given to rancor.

The second unusual feature of the 1972 hearings was the enormous increase in appropriations that NBS was allowed to request for fiscal 1973. The total came to $79 million, an increase over the previous year's budget by a whopping $30 million. After Branscomb made his formal presentation, Mr. Slack felt a need to check the facts:

> Mr. Slack: We realize that you are requesting funds here for some very worthwhile programs. However, when I read the amounts requested this year and compare those with the appropriations made last year I find this is an increase of almost 60 %. Is that correct?
>
> Mr. Branscomb: That is correct, Mr. Chairman.
>
> Mr. Slack: That is a very sizable request.
>
> Mr. Branscomb: It is, Sir.

[62] 1972 Funds-requested data from Hearings, House Approp. Subcomm, April 20, 1971, p. 1118, "1972 Estimate; $47. 5 million." 1972 Funds-appropriated data from Hearings, House Approp. Subcomm., March 28, 1972, p. 1076, "1972 Approp.; $49.8 million."

[63] Hearings, Subcommittee, Part 3, Commerce, March 20, 1972, p. 15.

A third remarkable feature of the 1972 hearings only became known a week later, when Branscomb's resignation as NBS Director reached the White House. Having created momentum for recognition of the Bureau's present and potential role as a leader for technological progress in the U.S. government and having obtained executive-branch support for a notable increase in funding to help fulfill that role, Branscomb had set a stage that he would occupy no longer.

The $79 million budget request for NBS, Branscomb's narrative stated, was an unusual expansion meant to attack national problems of unusual magnitude—the decline in growth of U.S. productivity, the first trade deficit of the century, environmental pollution, and public safety.

Largest of the new program proposals originated with "the President's initiative to focus scientific research and technology more directly on solving national problems."[64] In fact, it was one proposal that had not been initiated by Branscomb—nor by anyone at NBS, for that matter. Lawrence Kushner, Deputy Director of NBS, remembered receiving a telephone call from the Office of Management and Budget while Branscomb was on foreign travel; the caller announced that $8 million would be added to the fiscal 1973 budget for a program that would help innovation in U.S. industry by eliminating barriers to technological progress. Kushner promised to begin immediately to design such a program, but the caller needed a program title at that moment. During that call, the Experimental Technology Incentives Program (ETIP) was born.[65]

The nature of the ETIP program was developed principally by Edward J. Istvan, a newcomer to NBS[66] who was Associate Director for Teleprocessing in the Center for Computer Science and Technology. The main idea of the program became part of the NBS budget narrative for Fiscal 1973, with a price tag expanded to $14.4 million.[67]

Besides the ETIP program, an increase of $3 million was requested in programs collected under the heading "productivity enhancement." These included a new neutron-standards capability ($407,000), extension of the standard reference data program ($534,000), expansion of the computer science and technology program ($1.05 M), and a new cryogenics-based electric-power project ($1 M).

$1.5 M was asked in the area of environmental-pollution abatement. The Measures for Air Quality program was to receive about one-third of that increase, another third was earmarked for water-pollution work, and the rest was intended for studies in noise pollution.

[64] Hearings transcript, p. 1077.

[65] Lawrence Kushner, Oral History, June 7, 1988.

[66] Istvan joined NBS in 1971. He was an expert in the use of radar for meteorological work. He had experience in the Air Weather Service, in the Guided Missile office of the U.S. Air Force, in the Department of Defense Office of Space Systems, and at the Communications Satellite Corporation.

[67] Hearings, House Subcommittee, March 28, 1972, p. 1085.

Programs in public health and safety were scheduled for increases totaling $6.4 M. Research projects in the areas of materials measurements ($725,000), failure avoidance ($1.2 M), fire research and safety ($3.8 M), and radiation safety ($400,000) were intended to share in this funding.

Improvements in the NBS plant and equipment were scheduled to cost $5.3 M; of that amount, $4.2 M was intended to augment the NBS Working Capital Fund used to purchase general equipment. The rest was intended for a new volt standard, the time and frequency program, and reactor-facility plant improvements.[68]

The state of the Bureau's equipment had been found wanting in the extreme during a survey taken in preparation for the July 1970 meeting of the statutory Visiting Committee. Over the previous half-decade, the annual equipment expenditure for the Bureau's technical staff had dropped from roughly $1000 per scientist to $600. The Visiting Committee report stated:

> Although maintained with great care and devotion, the most that can be said of much of the equipment is that it has the beauty of a well-varnished buggy.[69]

Noting that the Committee had recommended an increase of three to five times the amount usually spent by NBS to bring its spending level for equipment up to the rate routinely allocated by comparable private-sector laboratories, Secretary of Commerce Maurice Stans urged Congress to fund a five-year modernization program.

NBS Staffing and Funding Levels under Branscomb

It is fair to guess that it was the care with which Branscomb prepared his testimony before Congress, coupled with his vision of NBS as a greater force in the day-to-day technological life of the United States, that provided much of the impetus for the Bureau's Fiscal 1973 Congressional appropriations. Too, Branscomb's efforts coincided with a growing awareness in both the Executive Branch and Congress that NBS could be of considerable service to the Nation's economic health, as we shall see.

Such are the thrills of government funding that, in March of 1972, NBS happily found itself allowed to seek $79 M (an increase of $30 M) in direct appropriations for Fiscal 1973. When the budget finally passed both houses of Congress, NBS had been granted over $69 M (including $10 M for the ETIP program).

However, before the Bureau could spend the $20 M increase over its Fiscal 1972 appropriation, President Nixon announced that $13 M of the increase would be required of NBS as part of a general economy drive in government spending.[70] The ETIP program—suggested, as noted above, by the President's own productivity-enhancement effort—gave up only $3.8 M. Entirely gone were the increases for

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[68] House Subcommittee hearings, March 28, 1972, pp. 1078-1087.

[69] Letter to Stans from Robert L. Sproull, Chairman of the Visiting Committee, June 22, 1971. RHA Director's Files, Box 390, Folder July 1971.

[70] News accounts at the time referred to the cuts as "impoundments" or "rescissions." The transcript in the 1974 House Subcommittee hearings recorded the cuts as "savings and deferrals."

neutron standards; for standard reference data; for computer sciences; for radiation safety; and for the volt standard, reactor, and time and frequency dissemination facilities. The environmental pollution standards program increase was cut back to $675,000. The cryogenic power program increase was reduced to $300,000. The appropriated increase to the fire program was cut by two-thirds.[71]

A worse problem than President Nixon's rescission of two-thirds of its Fiscal 1973 budget increase was his imposition, late in 1971, of 5 % reductions in both total numbers of Bureau employees and their average grade level. Through no fault of Lewis Branscomb, the Bureau lost more than 100 staff members during 1971-72, the equivalent of one of its technical divisions.

What to do about the budget, by the time the President's cuts in it were announced, was no longer the problem of Lewis Branscomb.

New Congressional Oversight Hearings for NBS

Even prior to his appointment as director, Lewis Branscomb held the view that NBS program support in Congress suffered because its work was so little known by individual Congressmen. In order to make ends meet, NBS managers were more and more often forced to accept funding from other government agencies as a means to pursue projects that could advance the Bureau's basic mission. Other-agency funds then constituted about 42 % of the total Bureau support—too high a figure by far, by Branscomb's reckoning.

If only members of Congress were better informed about NBS, they would be more likely to provide the agency with adequate support through direct appropriations, thought Branscomb. As its new director, he already knew well the high quality of the NBS staff and the broad range of its programs, and he welcomed the visibility that public scrutiny would bring.

Tickling the system in September of 1971, Branscomb inquired whether the House Committee on Science and Astronautics would be interested in celebrating the Bureau's 70th anniversary "by undertaking an in-depth review of the Bureau of Standards—the goals, structure, operations, strengths, problems, and opportunities."[72] Allen Astin also urged the Committee to act.

Extensive familiarization hearings had been undertaken by the House Committee on Science and Astronautics in 1959, during the year following its establishment. These had been the last comprehensive Congressional reviews of the Bureau, although limited hearings had occurred numerous times since then. Perhaps most significant were those held in 1961 in connection with the provision of large-force calibrations for the space program, in 1964 to accompany the initiation of the Standard Reference Data program, and in 1967 as part of the development of the Metric Study legislation.

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[71] House Subcommittee hearings, April 17, 1973, p. 772.

[72] LMB, "Perspective" *SP 825*, p. 25.

Branscomb's inquiry was received with enthusiasm. The Congressional Research Service (CRS), the investigative arm of the Library of Congress, was directed by the House Committee on Science and Astronautics to prepare a study of the Bureau for its Subcommittee on Science, Research, and Development.

Lester S. Jayson, Director of the CRS, assigned analyst Dorothy M. Bates to conduct the study. She collaborated in the review with Warren H. Donnelly and with Charles S. Sheldon II, Chief of the Science Policy Research Division. Their report was submitted to John W. Davis, chairman of the subcommittee, on August 18, 1971.[73]

The CRS report, intended to provide background information for the use of the subcommittee in conducting its oversight hearings, was detailed and thorough. One topic treated early in the report summarized the previous reviews of NBS by the Science and Astronautics Committee; it is worthwhile to note the highlights of those reviews.

Previous Reviews of NBS

The Congressional Research Service briefly recounted the findings of the Science and Astronautics Committee in hearings from 1959. The esteem with which NBS was perceived by the committee during those earlier hearings was indicated by the relatively few criticisms of the Bureau in the CRS summaries. For the most part, the committee members simply reported that NBS needed funding, or that NBS would be required to develop a new capability.

1959 Review

The latest comprehensive Congressional reviews of the Bureau, as noted above, had been performed by the House Committee on Science and Astronautics. The 3-day review in May 1959 had elicited a 13-page report by the Committee.[74] Committee members found no fault with NBS, only observing that:

> The Bureau's major problems related to the inadequacies of its physical plant and research and testing facilities at its old site on Connecticut Avenue in Washington. Major equipment critically needed in 1959 were larger 'dead-weight' machines to calibrate force measurements for the missile and rocket program, and a nuclear research reactor.[75]

[73] Congressional Research Service, Science Policy Research Division, Library of Congress, *National Bureau of Standards: Review of Its Organization and Operations: A Study Prepared for the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, U.S. House of Representatives*, 92nd Congress, First Session, September 8, 1971, 222 pp.

[74] Briefing by the National Bureau of Standards, 86th Cong. 1st sess. 1959 (May 7, 8, and 21), 78 pp.

[75] Briefing by National Bureau of Standards, 86th Cong. 1st sess., Aug. 21, 1959, 13 pp.

1961 Review

A second Committee hearing—in May 1961—had focused on the responsibilities of NBS to help the space program, testifying to the urgency of a technical response to the Soviet launch of Sputnik. In its report on the review, the Committee had noted that NBS was hard-pressed to keep pace with demands for its services, for numerous reasons:

- Lack of adequate funding.
- Limited and inadequate laboratory facilities.
- Necessity to perform work for other agencies to the detriment of its primary measurement-standards mission.
- Difficulty in recruiting and retaining additional senior scientists because of a lack of high-level positions.
- Inability to invest in backup research.

In view of these problems, the 1961 Committee recommended doubling the 1959 level ($15 M) of NBS appropriations in order to shift NBS staff from other-agency work to projects in the basic NBS mission areas.[76]

Subsequent Congressional Reviews

The CRS report noted that other Congressional hearings on NBS in subsequent years had been confined to specific aspects of its programs. These included the following:

- Amendment of the Organic Act in 1963 to give NBS authority to carry funds past the end of the fiscal year, to allow visiting scientists to work at the Bureau, and to allow NBS to receive and spend gifts and bequests.
- Hearings in 1966 that led to the establishment of the Standard Reference Data System.
- Hearings in June, 1967, that led to an amendment of the Organic Act to authorize a Fire Research and Safety program.
- Hearings that led to enactment of Public Law 90-472, the Metric Study Act, in 1968.

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[76] Direct Congressional support for NBS research and technical services during the three-year period 1959-61 did rise dramatically, although it did not double:

Year	1959[a]	1960[b]	1961[c]
Res. & Tech. services	$11.5	$17.3	$18.8
Plant & Constr.	$ 3.7	$ 2.1	$25.5
Total Amount (millions)	$15.2	$19.4	$44.3

Notes:

[a] Hearings, House Appropriations Subcommittee, 86th Cong., 1st sess., May 1, 1959, pp. 250-251.

[b] Hearings, House Appropriations Subcommittee, 86th Cong., 2nd sess., January 13, 1960, pp. 234-236. Across-the-board increases for all technical areas averaged 30 %.

[c] Hearings, House Appropriations Subcommittee, 87th Cong., 1st sess., May 3, 1961, pp. 807-808. The "Plant and Construction" item includes new facilities—nuclear reactor, deadweight-testing building, and linac—at the Gaithersburg site.

Executive Branch Reviews

The Executive Branch conducted its own reviews of NBS. The CRS report duly summarized these reviews:

- Annual reviews by the statutory Visiting Committee, for the Secretary of Commerce.
- Annual reviews of technical divisions by evaluation panels administered by the National Research Council.
- Occasional reviews by the General Accounting Office.
- Two major reviews made at the request of Secretary of Commerce Sinclair Weeks; an Ad Hoc Committee review following the AD-X2 battery-additive controversy (the first Kelly Committee review, in 1953), and a follow-up review (the second Kelly Committee review, in 1958).[77]

The CRS report identified the total paid staff at NBS in June 1970 as 4053 persons, including full-time permanent staff, Postdoctoral Research Associates, and part-time staff; 650 of these worked at the Boulder site.

More than 40 % of the overall Bureau support came from funding provided by other government agencies and from testing fees. (Branscomb believed that outside support should be capped at about one-third of the total support level.)[78]

NBS appropriations were authorized by the House and Senate Appropriations Committees, Subcommittees for the Departments of State, Justice, Commerce, the Judiciary and related agencies. The subcommittees were chaired by Sen. John L. McClellan and John J. Rooney. The fiscal 1972 appropriation for NBS totalled $48 million, including $47 million for research and technical services; overall NBS support was in excess of $85 million.

The report took notice of the new budgetary line items used by Branscomb during the House Appropriations Subcommittee hearings in April 1971.

In the CRS overview of the quality of NBS as a federal agency, the authors stated that they found:

> . . . no serious shortcomings or inadequacies for which the Bureau can be held responsible. But there are problems confronting the Bureau which, if left unattended, may result in difficulties not only for the Bureau, but for the Nation as a whole.

[77] Extensive discussion of the two Kelly Committee reports on NBS programs and management can be found in Passaglia, *A Unique Institution*. See, for example, p. 173 and p. 304.

[78] LMB, Oral History, July 12, 1988.

The authors alluded to difficulty in "getting a grip" on the Bureau because, as Branscomb had surmised, outsiders knew relatively little about its work.[79] In addition, it appeared that the Bureau's operations—already more technical and diverse than the average citizen could follow—changed quickly in response to requests from governmental or technical organizations. The result was the relative obscurity that Branscomb wished to overcome.

The existing and foreseeable "Bureau problems" mentioned in the CRS report derived in the main from sources external to NBS. One such was uncertainty and, often, inadequacy in funding, arising in part from the fact that the NBS mission—while important to the Nation's technological well-being—often lacked the glamour of, say, a space trip to the moon. Another lay in the diversity of its responsibilities to government and industry. A third reflected hesitancy on the part of Congress to increase support of civilian technology as the Nation's technological expenditures increased. Finally, the report mentioned the continuing demand that the Bureau should provide the measurement infrastructure to support these technological changes despite the difficulties of expanding or quickly adapting its staff to new projects.

The authors found a few areas where NBS efforts had been criticized during the past decade. There had been Congressional or industry dissatisfaction with certain features of the Bureau's work on Operation Breakthrough and the Flammable Fabrics project. A panel of the National Academy of Science had determined that the NBS materials-research facilities were inadequate. Demographic data had indicated that minorities were under-represented on the Bureau staff. Progress in deriving standards for automatic data processing had been slow. Differences with the General Accounting Office on fiscal procedures had occurred. And in certain cases, inequitable calibration-fee charges had been levied by NBS. All of these were suggested as suitable subjects for discussion during oversight hearings.

A number of additional avenues for Congressional inquiry were suggested in the report. These covered a multitude of thorny issues: adequate planning for the future of programs and standards; the continuing problem of the proper role of NBS in U.S. metric conversion; developing techniques for maintaining suitable levels of funding and laboratory facilities; questioning whether the Department of Commerce still provided the best "home" for NBS within the Executive Branch; and possible changes in Bureau authority and policy to help it to meet its responsibilities.

Oversight Hearings Testimony

The oversight hearings themselves took place September 16, 21, 22, 23, and 28, 1971 before the House Subcommittee on Science, Research, and Development. The record of the hearings ran to more than 380 pages.[80] Besides Branscomb, a host of witnesses testified on one topic or another. The list included the following people:

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[79] Branscomb was surprised that the authors of the CRS report did not consult with NBS managers in preparing it. The report would have been improved in several aspects, in Branscomb's opinion (see L. M. Branscomb, Oral History, July 13, 1988), had the authors buttressed information gleaned from external sources with amplifying material from NBS.

[80] House Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, *National Bureau of Standards Oversight Hearings*, 92nd Congress, First Session, September 16, 21, 22, 23, and 28, 1971, 387 pp.

- James H. Wakelin, Jr., Assistant Secretary of Commerce for Science and Technology.
- Vico E. Henriques, Director of Standards, Business Equipment Manufacturers Association.
- Nathan Cohn, Executive Vice President, Leeds & Northrup Company.
- Robert S. Walleigh, NBS Director for Administration.
- Ernest Ambler, NBS Director of the Institute for Basic Standards.
- John D. Hoffman, NBS Director of the Institute for Materials Research.
- F. Karl Willenbrock, NBS Director of the Institute for Applied Technology.
- Edward L. Brady, NBS Associate Director for Information Programs.
- Former NBS Director Allen Astin.
- Ruth M. Davis, NBS Director of the Center for Computer Sciences and Technology.
- Lawrence M. Kushner, NBS Deputy Director.

All witnesses gave written and/or oral testimony. In addition, written statements were inserted into the hearings record by 11 other individuals.[81]

The Bureau had a good friend in James Wakelin, the Assistant Secretary of Commerce for Science and Technology. Wakelin, formerly a manager at the Office of Naval Research and the Naval Research Laboratory, was well aware of the close cooperation between NBS and the National Oceanographic and Atmospheric Administration in the area of data acquisition and analysis. In his testimony, he gave glowing praise to the work of NBS, stressing its importance to the technical aspects of U.S. industry and commerce.

By the time of the oversight hearings, Branscomb was 2 years into his term as Director. He had quickly become familiar with most of the Bureau's programs, and he spoke with equal eloquence regarding his own view of the significance of NBS work to the Nation's technical enterprise. On this subject, he had well-developed views that greatly interested the members of the Subcommittee.

[81] These individuals included Bernard M. Oliver, vice president of research and development, Hewlett-Packard Co.; C. Sutton Mullen, Jr., chief fire marshal, Bureau of Insurance, Virginia State Corporation Commission; N. Bruce Hannay, executive director of research, Bell Telephone Laboratories, Inc.; Michael M. Schoor, legislative assistant, American Dental Association; Harold B. Finger, Assistant Secretary for Research and Technology, Department of Housing and Urban Development; John E. Mock, Georgia Science and Technology Commission; Arthur M. Bueche, vice president for research and development, General Electric Co.; W. O. Baker, vice president for research, Bell Telephone Laboratories; W. T. Cavanaugh, managing director, American Society for Testing and Materials; Sava I. Sherr, manager, standards operations, Institute of Electrical and Electronic Engineers; and Roy P. Trowbridge, president, American National Standards Institute.

Branscomb's testimony in the oversight hearings was important principally because it placed before the Congressmen a multitude of ideas on how the Bureau perceived its mission and its relation to other government entities. Following are a few of his comments:

> *Mission of NBS*
>
> Our cornerstone responsibility is to provide for the United States the single authoritative source of accurate, compatible, and useful physical measurements and further to ensure their international compatibility.
>
> No nation in the modern world, much less the world's leading scientific and technological society, can prosper and function effectively if the national system of measurement is in a state of anarchy.
>
> The commercial life of this country depends upon the Bureau's help with such measurement problems, not alone because the Bureau's staff bring to bear scientific talents not usually found in industry, but more importantly because both buyer and seller need an unbiased, honest third party with the technical capability to say 'This measurement is a fair and accurate one; that one may not be.'[82]
>
> ***NBS Operating Goals and Objectives***
>
> - Measurement Services for Science and Technology.
> - Science and Technology for Industry and Government.
> - Technical Services for Equity in Trade.
> - Technical Services for Public Safety.
> - Technical Information Services.
> - Central Technical Support.
>
> ***NBS Budgeting Methods***
>
> The National Bureau of Standards was established and has operated much like a central corporate laboratory in the Federal Establishment.
>
> The National Bureau of Standards does not have a line appropriation for administrative operations and research in addition to its program budget. Nor does the Public Building Service budget for the maintenance of our facilities, which we operate out of project funds. Every dollar spent at the National Bureau of Standards is accounted for as a program cost.
>
> In addition, we provide a variety of reimbursable services for which we must incur no profit and no loss. For these programs, we require access to working capital to invest in inventory of both materials for sale and labor for services in progress.[83]

[82] Hearings Committee print, pp. 20, 22.

[83] Hearings Committee print, p. 38.

NBS Staffing Levels

During a time of rapid priority change and laboratory reorganization, our staff has been admirably adaptable. An annual reduction-in-force averaging about 1.5 % of our total personnel each of the last two fiscal years has been regrettable, but unavoidable.

Here is a chart that shows the rapidly growing Institute for Applied Technology, where, of course, a number of programs with pressing social priorities are located. If you will consider the tremendous efforts we have made to focus our talents on priority technical problems, not only to respond to changing social needs, but the changing requirements of science itself within the Institute for Basic Standards and the Institute for Materials Research, whose staffs have been declining slowly, you will appreciate that our staff has been called upon for adaptability.

We have also seen severe attrition in discretionary operating funds over and above our basic technical and support payroll. This, in part, has forced the reductions-in-force as managers reduce staff to keep operational efficiency.[84]

Between 1965 and 1971, the Bureau staff grew slightly, from 1369 to 1384. But the Institute for Applied Technology in that interval grew from 139 to 349, the Institute for Materials Research held almost exactly constant, and the Institute for Basic Standards—concerned with the provision for the central basis for measurement in this country—dropped from 687 to 562.

This trend in itself is simply descriptive of the narrowing of our base of measuring services for science and technology, and it does give me pause. The static nature of the total professional staff simply spells a picture of a talented, experienced staff slowly growing older and failing to replenish itself adequately with recently educated younger graduates. We are attempting to do whatever we can within the constraints of a more or less constant staff to insure our vitality.[85]

NBS Equipment

At the same time, we have permitted the state of the Bureau's equipment to fall far below the standard to which industrial laboratories maintain themselves, notwithstanding the fact that it is our responsibility to be the measurement laboratory for them.[86]

In our Metallurgy Division, for example, we feel that a very high priority should be given to fracture mechanics, fatigue, and related problems. We are now trying to strengthen our capabilities in this area under the general heading of failure avoidance services.

[84] Hearings, Committee print, p. 40. From Branscomb's answers to questions by the Committee, it is clear that "social" projects at NBS refer to relatively short-term programs such as flammable fabrics, fire research and safety, and building codes. Most of this work was mandated by Congressional legislation.

[85] Hearings, Committee print, p. 317.

[86] Hearings, Committee print, p. 40.

I have looked at the age of equipment used in this program. We have all of our equipment on a computer roster and can query this roster for the acquisition date. My staff provided me with a page and a half of equipment items, starting with the first one acquired, and the list ends in 1909. Several items on that list are fatigue testers and tensile testers still in use. My staff informs me that although we do have the personnel in metallurgy, we are not in a position to undertake work in fracture mechanics because of the lack of, or the total obsolescence of, appropriate test equipment.

If I may show the committee one figure, I would like to indicate that our National Academy of Sciences' evaluation panels have been very helpful in calling this problem to our attention. They also have helped to provide us with some base of overall judgment by which we can calibrate our impression, based on the individual requirements of the laboratories, that we are underfunded in equipment. We obtained information from a number of industrial laboratories with similar types of research programs.

Examples would be Bell Telephone, General Electric, or Westinghouse. They invest 10 % in general equipment for the laboratories. That is indicated by the horizontal line. The vertical bars give the percentage that NBS has invested in equipment over recent years. The number has risen and fallen (in the range 2 % to 8 %).[87]

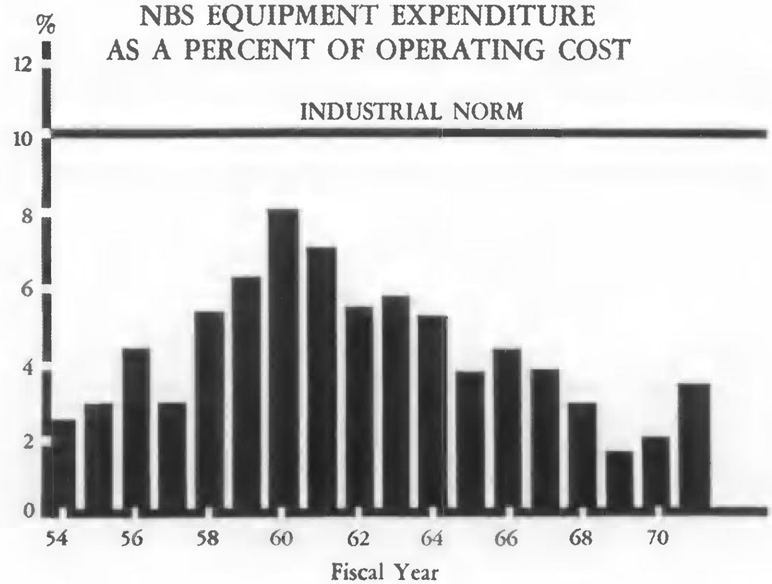

Chart shown by Lewis Branscomb to the House Subcommittee on Science, Research, and Development during 1971 Oversight Hearings. It demonstrated the relatively low investment in NBS laboratory equipment from 1954 to 1971 compared with expenditures by major private-sector laboratories.

[87] Hearings, Committee print, p. 319-320.

Prospects for NBS

I am a strong advocate of a businesslike mode of operation in which all costs are charged to projects. I would only like to make it clear to the committee that the fiscal pressure under which we have operated in the last several years—and will probably continue to operate—will require continued cancellation of both programs and competences in many significant areas, areas where sections of our scientific and engineering community have depended upon us for continued assistance. Your oversight of these choices is appropriate too.

Despite these difficulties I believe the National Bureau of Standards faces the most challenging opportunity of any large research laboratory in this Nation. We have the right competence in the right organization at a right time. We are effectively engaged in a way that I think is unique in bringing science and technology to bear on national social and economic problems as well as on our scientific achievement.

Our scientists understand the complexities of the social context within which their research must find application. We enjoy a generally excellent reputation among those who know our work, even though we have not been very active in making ourselves known to the general public.

The public's expectations from science and technology multiply every day. But I am deeply concerned that disillusionment may follow if government fails to promote innovation and the productivity of our technology, and fails to guide the regulation of technology on the basis of objective evidence and fair and accurate measurements.

We see the national measurement system and a system of industrial and engineering standards as dynamic systems calling not for more stewardship, but for leadership. The National Bureau of Standards welcomes the guidance of this committee in how it can better provide that leadership.[88]

Branscomb's comments made it clear that NBS was doing more with fewer resources. His words were cogent testimony that the Bureau was running out of flexibility in the face of dwindling professional staff and insufficient or outdated equipment. The Committee questions indicated that they agreed with his assessment.

Ambler, Hoffman, Willenbrock, and Davis took turns explaining to the committee the nature of NBS programs under their care. The committee members expressed interest in the details of the Bureau's technical work and complimented the managers on the clarity of their presentations.

Edward Brady, NBS Associate Director for Information Programs, gave an overview of NBS activities, lodging them within the framework of national needs. Brady noted the benefits to society from the Bureau's work—enhanced productivity, improved health and safety, and better-made consumer products. He closed with a brief exposition of NBS technical communications—publications, conferences, and seminars.

[88] Hearings, Committee print, p. 40.

On the third day of the hearings, Allen Astin testified. In his written remarks, the former Director addressed a recurring question: Should NBS be moved from the Department of Commerce? His view was that, while the Bureau's scientific cooperation with organizations such as the National Science Foundation and the National Aeronautics and Space Administration could not reach their full potential while NBS was lodged within DoC, Bureau programs were vital to the success of so many DoC activities that only an Executive-branch reorganization could improve the present situation.

Astin reminded the committee members that the Bureau had served as a veritable hothouse of innovative technology during his 17-year term as director, creating new technical organizations and then spinning them off to other agencies. These included the guided-missile laboratory, sent complete with equipment and staff to the U.S. Navy; the Diamond Ordnance Fuze Laboratory, similarly given to the U.S. Army; the Institute for Numerical Analysis, which became part of the University of California at Los Angeles; an integrated-circuit electronics laboratory that became an industrial activity; the Central Radio Propagation Laboratory, which helped to create NOAA; and a product-testing laboratory that became part of the General Services Administration. He noted that, under new Director Branscomb, another spin-off had already taken place—the Bureau's vehicle-safety laboratory had been transferred to the Department of Transportation. All of these creations and divestitures, Astin stated, showed the determination of NBS to avoid accretion of staff and functions beyond its own view of its rightful mission.

Astin identified as a serious problem the tendency of Congress to assign programs to NBS with inadequate support. He noted that Congress had funded only 10 % of the amounts deemed essential to the success of six programs recently assigned to the Bureau, with the result that the programs had fizzled or the core competence of NBS had been eroded as its managers had struggled to implement them.[89] He also reminded the Committee that the Bureau's lack of adequate equipment had been noted by the Kelly Report in 1953, but that the revolving fund for equipment had hardly been augmented during the intervening decade. Certainly, he said, NBS was well below the average for a modern U.S. laboratory in terms of its per-scientist equipment allocations.

Significant in the light of the eventual change in the name of NBS was a comment by Astin that:

> Part of the difficulty in some of the lack of appreciation of the range of the Bureau programs and services is the name—The National Bureau of Standards. Some Secretaries of Commerce, on learning of the scope and importance of the Bureau activities, have suggested that we devise a new and more descriptive

[89] Charles A. Mosher, member of both the Subcommittee and the parent Committee, expressed disappointment later in the hearings (p. 227 of the official transcript) that there existed "a serious lack of coordination between the authorizing committees and the appropriating committees . . . that is at the very core of failure of congressional effectiveness in this field."

name. I have viewed such suggestions with mixed thoughts. I can definitely see several advantages to a broader name. On the other hand, the present name is held in high regard by the Bureau's specialized clients and there is danger of losing some of this with a new name.

I would want to retain the word "Standards" in any new title. However, our counterpart laboratories in England and Germany have the names National Physical Laboratory and Physikalisch-Technische Bundesanstalt, respectively, and the word "standards" does not appear.

Perhaps, nearly two decades later, Astin's remark played a role in Congress' decision to rename the Bureau.

NBS Deputy Director Lawrence Kushner spoke on the fourth day of the oversight hearings. He responded to the committee's desire for more specific information on the NBS role in the development of engineering standards. He carefully drew the distinction between standards of physical measurement—the lifeblood of the metrological sciences and the benchmarks of the laboratory sciences—and engineering standards, which undergird industrial practices regarding product manufacture and performance, safety, pollution-generation, and dozens of other commercial areas. He noted that, in the United States, most engineering standards were voluntary—their major influence being found in the agreements among companies and nations that their work should conform to the standards.

Members of the committee heard about the American Society for Testing and Materials, the American National Standards Institute, the Society of Automotive Engineers, the Institute of Electrical and Electronic Engineers, Inc., and a host of other organizations created to advance the cause of standard practices.

Kushner described the types of service given to engineering standards by some 350 NBS staff members, working with more than 900 committees in one or more of 400 standards-writing organizations. Mostly, he stated, Bureau participants provided technical expertise, lending their knowledge of measurement limits and instrumentation. Committee members expressed satisfaction with his clear discussion.[90]

After five days of detailed testimony, the Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics, 92nd Congress, had received an enormous amount of information about NBS. The picture painted for them by the speakers described an agency with a strong sense of its own mission and a willingness to fulfill that mission by dint of careful and diligent work.[91] NBS, both in Gaithersburg and in Boulder, was described as possessing a talented group of scientists and engineers housed in excellent facilities.

The Committee also heard much about the needs of the Bureau for more and better equipment and for amplified funding for its staff. Whether the oversight hearings would help the Bureau shed the cloak of invisibility that kept from it a more productive level of support, only time would tell.

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[90] Hearings, Committee print, pp. 281-294.

[91] Synopses of the testimony presented by NBS speakers were recorded in the 1971 Annual Report, published as *NBS Special Publication 360,* June 1972, 90 pp.

An Unexpected Departure

The news, reported in *Science* magazine, came with stunning swiftness:

> The President's technology opportunities program, which was unveiled early this year, assigned a lead role to NBS, marking what was probably the first time the bureau has starred in any program of national prominence. Lewis M. Branscomb, the man who aroused the low-profile and somewhat sleepy agency to such eminence after only 2 1/2 years as its director, announced last week he is leaving to become vice-president and chief scientist of IBM. This decision, which Branscomb explains as "a personal opportunity for me that is not likely to come again," will deprive the Washington science scene of one of its rising and brighter stars. IBM did not have to scour the length and breadth of the nation for its new executive. Emanuel R. Piore, present chief scientist at IBM and a doyen of American statesmen of science, is a member of the NBS visiting committee. An atomic physicist, not a computer technologist by trade, Branscomb will direct IBM's research on a strategic rather than a tactical basis. IBM spends roughly $500 million a year on research and development, compared with a total budget of less than $50 million enjoyed by the NBS. Branscomb thus steps into a job that is ten times larger and, it is said, will roughly double his present salary of $36,000. Since becoming director of the NBS in June 1969, he has turned down at least two university presidencies and has been in the running for the presidency of the Massachusetts Institute of Technology and the directorship of the National Science Foundation.[92]

One week later, the *NBS Standard* published a special edition containing copies of Branscomb's letter to President Nixon, resigning his position:

> It is with regret, even with misgiving, that at such a time of opportunity for further public service I ask you to accept my resignation at a date of your convenience. But my feelings of obligation to Government service are matched by my conviction that the private sector also offers significant opportunities to contribute to the national welfare.
>
> The knowledge that through your leadership the great capabilities of the National Bureau of Standards' scientific staff will be fully utilized in the public interest makes this difficult decision possible for me.[93]

The same issue continued with President Nixon's acceptance:

> Dear Dr. Branscomb: Your letter of April 4 has come to my attention, and it is with special regret that I accept your resignation effective upon a date to be determined. Few men in government have contributed so much to the Nation's well-being as you have done with such brilliance and dedication for the past twenty years.[94]

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[92] Nicholas Wade, "NBS Loses Branscomb to IBM," *Science* **176**, April 14, 1972, p. 147.

[93] Letter, April 4, 1972, LMB to the President. Reprinted in *NBS Technical News Bulletin* Vol XVII, No. 4, April 20, 1972.

[94] Letter, April 5, 1972, President Nixon to LMB. Reprinted in *NBS Technical News Bulletin* Vol XVII, No. 4, April 20, 1972.

In a farewell to his division chiefs, Branscomb stated, "I leave only because of a unique opportunity for me and my family."

He expressed great confidence that NBS was on the brink of a new role in U.S. technology: a large budget increase pending; the absolute confidence of Peter G. Peterson, newly appointed as Secretary of Commerce, and of President Nixon; and a solid, competent management. He warned the chiefs that "If the Bureau's function is to assist in this [national technological, social, and economic] change, it is unthinkable that the laboratory itself would not change with the circumstances."[95]

By the end of May 1972, Branscomb was gone.

Assessing Branscomb's Directorship

Nearly every staff member at the Bureau was both surprised and disappointed by the news of Branscomb's sudden resignation. His personality and his ability to represent NBS effectively to congressmen and to other outsiders had created a vision of unprecedented stature for the agency. Many Bureau employees felt that Branscomb was justified to leave NBS, in view of the significance of his new position and the promise of financial well-being indicated by its title. Others, most definitely including former director Allen Astin,[96] were well aware that many senior Bureau scientists routinely received offers of prestigious and well-paying jobs elsewhere and felt that leaving NBS for such an offer was in some way a desertion in time of battle by Branscomb.

Old-timers on the NBS staff had been concerned immediately after Branscomb's appointment by his statements describing the Bureau in terms of solving short-range national problems, rather than stressing the purely scientific nature of the institution. Branscomb had addressed the paradox implicit in these criticisms directly, during his first address to the staff:

> I have been aware of the widespread view that the new activities in technology introduce an alien, and some would say incompatible, dimension into NBS—a set of programs essentially different in character from those that have gone before. But the more I look into the problem of fostering innovation—or, if you prefer, encouraging engineering creativity in the solution of practical problems—the more I find that the cure calls for the science of measurement once again, and often at a high level of sophistication.

Branscomb illustrated this idea with an example chosen from building technology's efforts on behalf of performance-based standards:

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[95] "Excerpts from Dr. Branscomb's announcement to division chiefs," Reprinted in *NBS Technical News Bulletin* Vol XVII, No. 4, April 20, 1972.

[96] Recollection of Elio Passaglia from a personal interview with Astin.

> A performance standard is meaningless without a reliable, quantitative measurement to be used in certifying the performance. To develop such test methods is a demanding task, requiring original research and imaginative thinking.[97]

Thus, Branscomb refused to divide Bureau work into "basic" (i.e., good) and "applied" (i.e., less good) projects, preferring to look for creativity and challenge in any assigned or self-generated project.

Opinion of observers outside NBS on Branscomb's departure was typified by Daniel Greenberg, editor of *Science and Government Report*, a science-news periodical:

> Branscomb, much sought after by recruiters for university presidencies, was widely regarded as one of the most capable and innovative of government administrators, and at NBS there is no little annoyance about his leaving in the midst of the efforts he inspired to shake some life into that venerable establishment.[98]

Branscomb was an active, hands-on administrator during his brief tenure as NBS Director, though not spectacularly more involved in the Bureau's management than his predecessor. His genius was to devise new procedures to make the Bureau more effective in managing and presenting itself: an Executive Board explicitly charged to participate in total oversight of the Bureau; a Programs Office explicitly charged with measuring Bureau projects against a standard of effectiveness created by its own efforts; and a results-oriented set of NBS goals chosen to relate Bureau work to public problems that Congress could more easily support.

Beyond his innovations in management, his involvement in many national scientific committees—coupled with an unusual verbal facility—allowed him to present his ideas with great force. His circle of acquaintances extended far beyond NBS; when he spoke, they listened with interest. It is to his credit that Branscomb continued to pursue vigorously a more effective use of technology and better technical education throughout the U.S. technical establishment, both in his position at IBM and later, while a Professor of Public Policy and Corporate Management at Harvard University.

The Next Step

After swallowing their amazement and disappointment at the loss of a leader in whom great hopes had been placed, the realists who made up the great majority of scientists at NBS considered the logical next step. Not necessarily who should become the next Bureau director—the President's prerogative, after all—but what course the Bureau should take, and what strategy could succeed for it.

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[97] Lewis M. Branscomb, "Dr. Branscomb: The Future of NBS—Excerpts," *The NBS Standard*, Vol XIV, No. 10, October 1969, pp. 1, 3, 4.

[98] Daniel S. Greenberg, "Branscomb Leaves NBS For IBM Post," *Science and Government Report*, April 15, 1972, p. 3.

Leaders there were at NBS, and good ones. Perhaps most visible was Lawrence Kushner, Deputy Director under both Astin and Branscomb. Kushner's credentials were impressive. Armed with a doctorate in physical chemistry from Princeton University, he had practiced his science at the Bureau since 1948. Within a few years, he had created an innovative surface-chemistry group within the Physical Chemistry Division. He was similarly productive in establishing a metal-physics group shortly thereafter in the Metallurgy Division. He served as chief of the Metallurgy Division from 1961 to 1966; while so serving, he assisted the Organization for Economic Cooperation and Development in assessing the quality of graduate education in metal physics throughout the world. During 1964-65 he worked as Special Assistant for legislative activity under J. Herbert Hollomon, the Department of Commerce Assistant Secretary for Science and Technology. Prior to becoming NBS Deputy Director under Allen Astin in 1969 he served as Deputy Director and Director of the Bureau's Institute for Applied Technology for three years.

Also a veteran of service with the Federal Council for Science and Technology, with the National Research Council, and various interagency panels, Kushner was clearly a potential replacement for Branscomb.

The Bureau had other logical choices, too, for Director—Ernest Ambler, John Hoffman, Edward Brady, and Howard Sorrows perhaps first among them.

Even more important was the overall quality of NBS management. Chosen by Astin or Branscomb, all knew their jobs and were resourceful leaders. The Bureau would survive the loss of Branscomb.

It is instructive to hear Branscomb's later comments on the circumstances of his sudden departure:

> I was offered [in December 1971 or January 1972] the job as Chief Scientist of IBM—which is sort of a non-turn-downable job. It is the best technical job in America. I told Vensen Learsen, the Chairman of IBM, that if I came, I would have to postpone coming until after I had seen this budget through,[99] because I owed that to my colleagues, indeed to the President, who had put my 36 % increase in his budget.[100]

Branscomb was easily able to rationalize his decision to leave. Two factors came to his mind in later years: one was that, as a Democrat in an increasingly partisan Republican administration, he might well have been removed from his position as a routine election-year measure, as was the director of the National Institutes of Health; a second was that he had always felt that wise use of technology was crucial to human progress, and that his new position at IBM gave him the best chance to help in this process.[101]

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[99] Recall that the House Appropriations Subcommittee hearings on the fiscal 1973 budget were conducted on March 28, 1972, with Branscomb as the principal NBS witness.

[100] Branscomb, Oral History, July 12, 1988.

[101] Branscomb, Oral History, July 12, 1988 and July 13, 1988.

TECHNICAL WORK OF THE BUREAU, 1969-1972

The work done by NBS scientists and engineers during the period when Lewis Branscomb was director reflected only dimly his struggle to achieve greater notice for the Bureau's efforts on behalf of the American public. There was no lack of successful projects that directly benefitted U.S. citizens, but NBS was not yet accustomed to the idea of publicizing its work with that viewpoint in mind.

Perhaps the NBS project that represented most broadly the national interest was undertaken to satisfy the demand from Congress to ascertain the Nation's posture on the desirability of the metric system for its everyday life. As we note in the next section, more than 50 members of the Bureau staff contributed in one way or another to the success of that information-gathering task. As part of a three-year program, they queried citizens in nearly every occupation about their personal measurement habits and desires.

But the major activities in the NBS laboratories in the period 1969-1972 lay in traditional Bureau areas of science and engineering—many of them, to be sure, of immediate benefit to consumers. Fire studies, conspicuous at the Bureau since its beginning, continued under the special impetus of a new congressional mandate. Research on buildings and other man-made structures continued to play a highly visible role at NBS. Law enforcement and automotive standards addressed specific needs of Americans. Reflecting the personal interest of its new director, the technologies involved in space and astronautics received concerted attention. More arcane studies such as the properties of matter dominated the work of whole divisions of scientists, as did measurement standards and fundamental probing into the laws of nature.

As was always the case at NBS, its output reflected in part the expressed needs of the public, voiced through congressional, industrial, and standards organizations. In part, too, Bureau output represented the sum total of the individual priorities and capabilities of its staff; their views of the technical world, highly personal and often deeply detailed, inevitably influenced their choices of project and emphasis.

The willingness of scientists to delve into scientific puzzles is illustrated in the coming discussion by a note on polywater, a bright but brief shooting star in the firmament of science. This material turned out to be not a new state of an old substance, but a collection of unexpected results brought forth by the unusual properties of water. As often happens, the resolution of the puzzle lay in improved measurements.

In the brief notes that follow, we present merely a taste from the whole technical menu offered by NBS during this period. It is our hope that some indication of the breadth and depth of the scientific enterprise that the Bureau embodied at this time is conveyed by these notes.

NBS Completes a " Metric System Study" for Congress

"*Metrify*, (transitive verb); 2. To convert to or adopt the metric system."[102]

As it had periodically since President Thomas Jefferson's first recommendation in 1795,[103] the U.S. Congress began to consider in the early 1960s the question of making the metric system mandatory for all Americans.

Congressional interest in metrification (also known by the names "metrication," "going metric" and "metric conversion") was piqued once again when the International System of Units (SI) was adopted in 1960 by the 11th General Conference on Weights and Measures, a diplomatic organization established in 1875 by the Meter Convention.[104] Chauvinistic hesitation to discard the "American" half-inch wrench in favor of a "foreign" twelve-millimeter model warred with the fear that American businessmen would be at a disadvantage in selling their products to "metric" countries abroad. And no doubt about it, America was becoming isolated in the use of "customary" units of measure (inches, miles, gallons, bushels, ounces and degrees Fahrenheit). All other industrial nations either had adopted the metric system (now consisting of seven base units—meter, kilogram, second, ampere, kelvin, mole, and candela—and an unending list of units derived from the base units) or had set a timetable for adoption. Only the United States and a baker's dozen of third-world countries retained non-decimal measurement systems.

The Problem

Congress was in a difficult position. America's mechanics and engineers had enormous inventories of inch-based tools and btu-based industrial practices; America's home-makers had a similar trove of teaspoons, Fahrenheit thermometers, and ounce-and-pint measures. America's homes, offices and factories were full of people who did not want to hear that their lifelong measurement practices were obsolete and that they needed to begin again in measurement kindergarten. Yet the message conveyed by the trend in international trade was clear: Europe and Asia wanted metric-based products and metric-based commercial discourse. What to do?

Claiborne Pell of Rhode Island led a discussion on this topic in the U.S. Senate for several years. George P. Miller of California expended similar effort in the House of Representatives.

Allen Astin, Director of NBS, called to testify during the Congressional deliberations, declined to advocate adoption of the metric system for the United States or to lobby against it. The Bureau, he testified, could best serve the debate by providing objective factual information on the system itself and its advantages and disadvantages.[105]

[102] Webster's II New Riverside University Dictionary, 1984.

[103] MFP, p. 532.

[104] Comptes Rendus des Seances de la Onzieme Conference Generale des Poids et Mesures, Paris 14-20 Octobre, 1960, pp. 65-88.

[105] Letter from AVA to John M. Cabot, Ambassador to Poland, January 27, 1964; Records Holding, RG167; Dir Off, Box 381; Chrono 1/64-4/64, Drawer 10.

In April 1975, Deputy Director Ernest Ambler (left) testified on metric conversion in the United States before the Subcommittee on Science, Research and Technology of the House Committee on Science and Technology. Commerce Department Counsel Robert Ellert joined Ambler at the witness table.

Seeing the rising interest in metrication in the Congress, however, Astin decided to be prepared for eventual NBS involvement. On June 9, 1965, he assigned Robert D. Huntoon, then Director of the Institute for Basic Standards, to develop a Bureau position and a plan for action.[106] He detailed Alvin G. McNish, Clarence N. Coates, Robert L. Stern and Malcolm W. Jensen to assist Huntoon in this task, and directed James E. Skillington, Chief of the Budget and Management Division, to help prepare budget estimates for any Bureau work that the task group might recommend.

The Solution

By 1968, a useful course of action for Congress—time-worn but effective—had become clear: it would commission a study. This one would be accomplished by NBS to determine the consequences of the various possible Congressional metric-system actions.

By June of 1968, Alvin McNish held the position of Assistant to the Director, NBS, for Metric Study. Astin assigned McNish and two assistants to refine the action plan for NBS should the pending Congressional efforts come to fruition.[107]

[106] Memo, AVA to R. D. Huntoon, June 9, 1965. NIST Records Holding RG 167; Director's Office; Box 381; Folder 5/1/65–7/30/65; Drawer 10.

[107] McNish, known internationally for his work on metrology and measurement science, retired in July 1970 after 34 years' service to NBS. Among his awards were the Presidential Certificate of Merit (1948), the Department of Commerce Gold Medal (1960), and recognition by the U.S. Office of Scientific Research and the U.S. Bureau of Ordnance. See "Alvin G. McNish Retires," *NBS Standard,* Vol XV, No. 10, October 1970, p. 7.

On the 9th of August 1968, the Congress passed the *Metric System Study Act, (82 Stat. 693; Public Law 90-472, 9 August 1968).* The one-page text contained a mountain of work for the Bureau. It authorized "... the Secretary of Commerce to make a study to determine advantages and disadvantages of increased use of the metric system in the United States." Calling for a program of "investigation, research, and survey," the act directed the Secretary to accomplish a number of tasks:

- Evaluate the advantages and disadvantages of the metric system for international trade, for the military, and for other international activities, and also within the United States.
- Compare the efficacy of the present system with the metric system for educational, engineering, manufacturing, commercial, public, and scientific uses.
- Assess the difficulty of switching to metric in the United States.
- Bring into the process representatives of U.S. industry, science, engineering, labor and government at all levels, as well as foreign governments and international organizations.

The act further required the Secretary to assess the consequences of metrification on the design of various U.S. products, to determine the extent to which the metric system already was used in America, and to recommend means to minimize costs and problems involved in switching to the metric system.

The act set a date of 9 August 1971 for a final report to the Congress, along with "... such recommendations as [the Secretary of Commerce] considers to be appropriate and in the best interests of the United States."

Up to $500,000 could be spent during the first year of the study; more Congressional funds might be forthcoming to support the second and third years of the study, depending on the disposition of Congress when the subsequent appropriations would be considered. The projected cost to NBS of participation in the Metric Study was estimated to be $2.5 M. Ultimately, however, expenditures at NBS for the Metric Study totaled just over $1.2 M.[108]

The "Metric" Team

Doing an honest job of satisfying the exhaustive requirements of the Metric System Study Act within the stated 3-year life of the project was clearly going to demand lots of work. Commerce Secretary Cyrus R. Smith was happy to delegate the task to the National Bureau of Standards, where this strange metric language was spoken daily and with great fluency. The Bureau, with its many connections to technical America, would provide a good focus for the project.

NBS took a full year to plan the Metric Study. Then, in just one year, the Metric team obtained the requested information, utilizing a multitude of conferences and meetings devoted to the different constituencies that had to be consulted. The final year was given to preparing and consolidating the lengthy set of reports that Congress wanted.

[108] See House Hearings FY71, pp. 1022-1023; and House Hearings FY72, p. 1146; House Hearings FY73, p. 1118.

On the day of the act's passage, Allen Astin had only a year to serve as Director. He could "get the ball rolling" before he retired.

Secretary Smith did his part by appointing a Metric System Study Panel of 45 members from across the spectrum of U.S. measurement activities. The panel was chaired by Louis F. Polk, a Director of the Bendix Corporation. Francis L. LaQue, former Vice-President of International Nickel Company, served as Vice-Chair, and Leonard S. Hardland of the NBS Office of Invention and Innovation was the panel Executive Secretary.

Astin's small advance-planning group was succeeded by an Advisory Task Force comprised of Walter E. Cushen, Daniel De Simone, Alan J. Goldman, Robert Huntoon, and Howard E. Morgan. Its report was delivered to Astin on March 21, 1969.[109]

New Director Lewis Branscomb substantially augmented the NBS Metric Study Group late in 1969. Soon the group included many experienced Bureau hands detailed from other projects. It is illuminating to see whence came the Bureau participants in the various Metric Study sections. The previous work assignment for each person is included parenthetically:

- Director of the Study:

Daniel V. De Simone (Chief of the Office of Invention and Innovation).

- Consultants:

Robert D. Huntoon (Assistant to the Director of the Bureau).

With his NBS colleagues Robert D. Stiehler (Product Evaluation Division), A. Allan Bates (Chief, Office of Engineering Standards Liaison) and Myron G. Domsitz (Chief, Electronic Instrumentation Division), Huntoon prepared an interim report on developments in international standards.

Alvin G. McNish (Chief of the Metrology Division).

Chester H. Page (Chief of the Electricity Division).

- Special Assistants:

George A. W. Boehm.

Florence M. Essers (Research Assistant to De Simone).

- Program Managers and their staffs:

Louis E. Barbrow (Consultant in photometry, Metrology Division) and Alvin McNish were co-leaders of the Manufacturing Industry section. Other Bureau staff assisting Barbrow and McNish included George C. Lovell (Office of Invention and Innovation), Robert R. Rohrs (Technical Analysis Division), Carolyn L. Flood (Office of Invention and Innovation), Alice B. Margeson (Office of the Director, NBS) and Judy M. Melvin (Electricity Division).

Roy E. Clark was leader of the section on Federal Civilian Agencies. Other Bureau staff assigned to this section included John M. Tascher (Chief of the Engineering Education Program, Office of Invention and Innovation), Joseph D. Crumlish (Chief of the Innovation Studies Program, Office of Invention and Innovation), Joseph P. Alexa (Office of Invention and Innovation), Jeanine Murphy, and Sandra Wean.

[109] AVA to Metric Advisory Task Force, April 16, 1969. NIST Records Holding; RG 167; Director's Office; Box 388; Folder March-April 1969; Drawer 10.

June R. Cornog (Behavioral Sciences Section, Technical Analysis Division) directed Elaine D. Bunten (Technical Analysis Division) in carrying out the Nonmanufacturing Business section of the Study. Other Bureau staff assisting them included Howard E. Morgan (Technical Analysis Division), William L. O'Neal (Analytical Chemistry Division), Lorraine S. Freeman (Supply Division) and Diane Beall.

Stephen L. Hatos (Office of Weights and Measures) carried out the Commercial Weights and Measures section of the Study.

Jeffrey V. Odom (Office of the Director, NBS) coordinated a series of conferences on the Metric Study. His NBS assistants included Bruce D. Rothrock, who headed the Labor and Consumers section of the Study; Robert W. Carson; Roy E. Clark: Joseph D. Crumlish (Chief of the Innovation Studies Program, Office of Invention and Innovation); Linda J. Luhn (Office of the Director, NBS); Jean M. Simon (Personnel Division); Debora L. Gilbert (Personnel Division); and Evelyn B. Tallerico.

Bruce D. Rothrock (Office of the Director, NBS; formerly in Length Section, Metrology Division) coordinated the section on Consumers. He was assisted by NBS employees Jeffrey V. Odom (Office of the Director, NBS); Robert W. Carson; Linda J. Luhn (Office of the Director, NBS); Jean M. Simon (Personnel Division); Debora L. Gilbert (Personnel Division); and Evelyn B. Tallerico.

Robert D. Stiehler (Consultant to the Chief, Product Evaluation Division) was responsible for the section on Engineering Standards. He was assisted by Bureau staff members Gustave Shapiro (Assistant to the Chief, Electronic Technology Division); Robert J. Klein (Electronic Technology Division); Harry Stoub; Arthur G. Strang (Chief of the Engineering Metrology Section, Metrology Division); and Theodore R. Young (Manager, Measurement Services Program, Metrology Division).

Charles F. Treat (Office of the Director, NBS) prepared a history of the metric system in America.

For many of the Bureau participants in the Metric Study, the assignment represented a full-time commitment for its duration. Others simply provided part-time advice or guidance on certain aspects of the study.

Not all the Study groups were composed of NBS staff members. A study on metrication in the Department of Defense was prepared by Leighton S. Lomas of the DoD and staffed from that department. Another study, on Metric Education, was prepared by the Education Development Center of Newton, Massachusetts; Berol L. Robinson of the EDC organization led the effort, assisted by professional educators and by Bruce Rothrock of NBS. A third, on Consumers, was prepared by the Survey Research Center of the University of Michigan under the direction of Professor George Katona. A fourth, on International Trade, was conducted by the Commerce Department Bureau of Domestic Commerce under the supervision of Thomas E. Murphy.

The Program

Details of the Metric Study plan, worked out by the original NBS group in concert with the Advisory Panel assembled by Commerce Secretary Smith, were completed in December 1969. It is interesting to note that, by then, the Secretary of Commerce was Maurice H. Stans and the new Director of NBS was Lewis Branscomb, both choices of new President Nixon. Despite this change in personnel at the top, the Metric Study continued on schedule.

The plan called for the Study to be carried out with the aid of questionnaires, personal interviews, and organized hearings in order to give every sector of U.S. society an opportunity to provide its information and to express its views on the questions raised by the Act. Some seven sets of hearings—called National Metric Study Conferences—and eleven special investigations were undertaken. Then the whole study project was digested and a massive report was submitted to Congress.

To properly carry out the wishes of Congress, each study group was required to probe deeply into its assigned area of the U.S.—or indeed the international—technical establishment. The various interest groups spanned the whole technical fabric of America:

- Labor.
- Consumers.
- Education.
- Construction.
- Engineering.
- Consumer Products Industry.
- Small Business.
- State & Local Government.
- Natural Resources.
- Health.
- Transportation.
- Other smaller groups.

Because of the tight schedule stipulated in the Act by Congress, barely one year was available in which the mass of factual data and opinion could be obtained. The third year was reserved for the actual preparation of the report and the recommendations of the Secretary of Commerce.

More than 700 organizations—labor groups, trade associations, professional societies, educational institutions, and consumer groups—were invited to participate in widely publicized hearings. The hearings occupied 20 full days during 1970; all but one were held in Washington, DC. Among some 200 individual presentations was one by Gordon Bowen, Director of the British Metrication Board, on the experiences in the United Kingdom with respect to "going metric."

Supplementing the hearings were special investigations in eleven areas. These investigations were conducted primarily through detailed questionnaires designed to elicit information about the use and attitudes of the queried organization, as well as more problematic estimates of the costs, benefits and disadvantages, and timing associated with the increased use of metric measures. Thousands of questionnaires were mailed to as many carefully selected representatives of the eleven sectors; follow-up questionnaires and personal contacts extended and verified the written results. Approximate numbers of responses are given in parentheses for each sector in which questionnaires were used:

- Manufacturing Industry (more than 3500 questionnaires).
- Non-manufacturing Businesses (more than 2000 questionnaires).
- Education (primarily based upon the results of a two-day conference held at NBS, augmented by detailed reports issued by the National Education Association and by the National Science Teachers Association).
- Consumers (about 1400 questionnaires).
- International Trade (over 400 questionnaires).
- Engineering Standards (based upon a comparison of International Standards Organization and International Electrotechnical Commission recommendations with the national standards of several countries, including the United States).
- International Standards.
- Department of Defense.
- Federal Civilian Agencies.
- Commercial Weights and Measures.
- History of the Metric System controversy in the United States.

As the various groups assessed the results of the thousands of individual and group queries undertaken during the Metric Study Act project, they found that most American manufacturers and nearly all scientists strongly favored a phased introduction of the metric system for America; these groups were using the system more and more each year. On the other hand, many small businesses and individuals expressed the fear that the changeover would be expensive for them. During 1971 these findings were documented in an exhaustive series of reports that were published as *NBS Special Publications.* It is instructive to briefly note the contents of these reports.

The first of the reports preceded the others by some months. It was a treatment of the impact of international standards on international trade and technology transfer.[110] The report was prepared by Huntoon and his NBS colleagues Stiehler, Bates and Domsitz with the collaboration of Allen Astin—by then the Director-Emeritus of NBS; Richard O. Simpson, Deputy Assistant Secretary of Commerce for Product Standards;

[110] "U.S. Metric Study Report: International Standards" U.S. Metric Study, Daniel V. De Simone, Director [Editor's Note: Although the title page does not so state, the text of the report was written by Robert D. Huntoon, Robert D. Stiehler, A. Allan Bates, and Myron G. Domsitz with the assistance of Richard O. Simpson, Allen V. Astin, and Donald L. Peyton], *NBS Special Publication 345-1*, December 1970, 145 pp.

and Donald L. Peyton, Managing Director of the American National Standards Institute. The report contained the conclusion that metric standards played an important, but not dominating, role in international trade. The process of product certification, they felt, would ultimately determine the significance of metrification for trade. Given the designation *Special Publication 345-1,* this report was issued in December 1970.

The views of the civilian agencies of the Federal government on metrification were described in a report written by Roy E. Clark, John M. Tascher, Joseph D. Crumlish, Joseph P. Alexa, Jeanine Murphy, and Sandra Wean.[111] The report highlighted the effects of metrification on some 15 areas of national responsibility of the civilian agencies, gleaned from questionnaires and/or from discussion with 55 such agencies. Many of the agencies queried already used the metric system to some extent. The general conclusion was that the metric system was the measurement scheme of the future, and that planned conversion to metric would be a preferred course of action over the policy of ignoring the measurement units problem altogether.

Stephen L. Hatos of the Office of Weights and Measures prepared a report on the effects of metrification on commercial weights and measures activities.[112] Hatos' study group received 15 detailed responses from manufacturers of devices used in weights and measures activities. Ten of those favored metrification, and they suggested that a mandatory program would probably be necessary in order to accomplish the task. Of 63 jurisdictions responding to the group's queries, forty favored increased use of metric measures. The National Conference on Weights and Measures, the professional organization that represented both sectors, was heavily involved in the study. The *Commercial Weights and Measures Report, NBS Special Publication 345-3,* recorded three recommendations: 1) If the United States should "go metric," a coordinated program, with target dates, should be established through the National Conference on Weights and Measures; 2) in the event of metric conversion, states should be encouraged to require metric packaging for various commodities; and 3) to achieve uniformity in packaging and labeling, Congress should first require dual labeling—metric and customary—and later require metric labeling with customary units optional. It was noted that some items—meats and cheeses, for example—are ordinarily packaged in random quantities, and that this practice should continue to be allowed.

The manufacturing sector was discussed in a report prepared by Louis Barbrow and Alvin McNish under the direction of Morris H. Hansen of Westat Research, Inc.[113] Hansen, a former Associate Director of the U.S. Bureau of the Census, was considered an expert on the use of statistical surveys. In a prefatory *"Critique on Metrication Cost Estimates in Manufacturing,"* McNish stated that the results of the group's cost

[111] "U.S. Metric Study Interim Report: Federal Government: Civilian Agencies," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-2,* July 1971, 317 pp.

[112] "U.S. Metric Study Interim Report: Commercial Weights and Measures," U.S. Metric Study, Daniel V. De Simone Director, *NBS Special Publication 345-3,* July 1971, 102 pp.

[113] "U.S. Metric Study Interim Report: The Manufacturing Industry," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-4,* July 1971, 141 pp.

In 1969, NBS Director Branscomb appointed Louis E. Barbrow (pictured here) and Alvin G. McNish to co-manage an especially critical component of the Metric Study which focused on the manufacturing sector.

questionnaires presented a "phantasmagoria" to the analysts. Estimated metrification costs ranged over a factor of 900, even excluding the pharmaceutical industry, which already made considerable use of metric measures. The report summary included the statement that larger manufacturers tended to use metric measures more intensively and to prefer it, whereas smaller ones were less likely to use the metric system and less likely to prefer it. Significantly, most manufacturers both large and small (70 % of all respondents) agreed with the statement that increased use of the metric system would be in the best interest of the United States.

The Non-manufacturing Business study was carried out by Elaine Bunten under the direction of June R. Cornog.[114] Information was obtained by telephone interviews with 2563 business firms chosen from Agriculture, Forestry, Fisheries, Mining, Construction, Transportation, Communication, Utilities, Wholesale and Retail Trade, Finance, Insurance, Real Estate, and Business and Personal Services. This group represented about 65 % of all U.S. employment. Remarkably, 90 % of the interviews

[114] "U.S. Metric Study Interim Report: Non-manufacturing Businesses," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-5*, by June R. Cornog and Elaine D. Bunten, July 1971, 184 pp.

yielded usable results. The interviews probed a number of areas: knowledge of the metric system; attitudes towards it; company "products"; company equipment and procedures; and hypothetical future use of metric measures and the problems and benefits thereof. About 75 % of the respondents had an "adequate" knowledge of the metric system. While a majority of respondents foresaw no particular difficulty in "going metric," about one in four expressed antipathy towards metric measure for their firm. Most firms saw employee retraining as the primary obstacle. Over 60 % of those queried expressed the view that increased use of metric measure was in the best interest of the U.S. and favored a mandatory (Congressionally legislated) change to metric measures.

The report on Education was prepared by the Education Development Center of Newton, Massachusetts under the direction of Berol L. Robinson.[115] In his Foreword, De Simone stated: "No other sector is so nearly unanimous in its endorsement of the metric system as is education." In fact, the text—written by a large group of distinguished educators—contained more discussion of the lack of effective instruction on measurement skills in the Nation's schools than it did on the desirability or problems of "going metric." The last two chapters of the Education report were entitled "A Program for Metric Conversion in Education" and "Education and a THINK METRIC Campaign."

Professor George Katona of the Survey Research Center at the University of Michigan was responsible for the preparation of the report on attitudes of the American consumer.[116] Katona and his staff addressed the questions: How much does the American consumer know about the metric system? What are their attitudes towards it? What are their opinions about metrification? Do they have preferences as to the methods that could be used to improve public knowledge of the system?

Many years of consumer research on a variety of topics had given Katona's group an advantage over other Study groups: he could simply append a questionnaire on metrification to a quarterly survey intended for about 1400 representative U.S. families. Knowledge of and experience with the system were probed, along with attitudes towards metrification for themselves and for the United States. He found that few consumers were familiar with metric measure and that most were loath to learn, although about half guessed that the metric system would be easier for students to master than the customary units. Only those respondents who were familiar with metric measures favored American conversion to the system.

A report prepared in the Bureau of Domestic Commerce of the Department of Commerce treated the impact of metrification on America's foreign trade. The report was drafted by Gerald F. Gordon under the supervision of Thomas E. Murphy.[117] Of the billions of dollars' worth of U.S. goods for export, only about 1 % were designed

[115] "U.S. Metric Study Interim Report: Education," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-6,* July 1971, 201 pp.

[116] "U.S. Metric Study Interim Report: The Consumer," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-7,* July 1971, 139 pp.

[117] "U.S. Metric Study Interim Report: International Trade," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-8,* July 1971, 173 pp.

and manufactured using metric measures, according to the survey of approximately 510 firms involved in international trade. On the other hand, about 19 % of imports were designed and built using customary units. The impact of the type of units used to make the goods was thought by the export/import firms to have little bearing on international trade in comparison with such factors as reputation of the trading firm for reliability, the level of technology built into the products, and their quality.

The report on metrification in the U.S. Defense Department was prepared under the leadership of the Air Force. Leighton Lomas, Chairman of the Department of Defense Metric Study, acknowledged the assistance of Vincent S. Roddy, his predecessor, and of two groups of DoD personnel in preparing the study: the DoD Steering Committee, composed of R. F. Dunbar, Jack L. Vogt, Winton E. Allen, Joseph L. Krieger, and James Brownell; and staff members H. J. Dickinson, H. G. Tinsley, A. P. Babbitt, and F. L. Ellison. [118] More than 125 groups from the Joint Chiefs of Staff, the Army, Navy, Air Force, Defense Supply Agency, National Security Agency, and other DoD agencies helped prepare the study under the supervision of the DoD Steering Committee. The report steadfastly refused to recommend either for or against metrification, but stated that the DoD could go metric only at considerable expense ($18 billion) and over a period of time. The DoD recommended that any program of metrification be a national one with a definite schedule, and that certain customary units with wide international acceptance be retained. Detailed discussions were presented of the advantages, disadvantages, and special problems—mostly connected with supply—during all phases of a metrification program.

An especially interesting report was written by Charles F. Treat of the NBS Director's Office. [119] Entitled "A History of the Metric System Controversy in the United States," the report provided a well-written account of the origins and development of both the customary and the metric system of measurement. The "battle of the standards" that flared periodically within the debates of Congress and through dedicated organizations—those favoring metrification for the United States as well as those opposed—was well documented; an extensive bibliography on the metric system and the controversy surrounding it was included. Treat closed with a synopsis of the arguments—some of them a century old—for and against the adoption of the metric system for America. We paraphrase the arguments here, since they retain their validity even today:

- The arguments "for":

1. Metric is a scientifically based decimal system.
2. Virtually the entire world excepting the United States uses metric measures.
3. Metrification is practical for the United States.

[118] "U.S. Metric Study Interim Report: Department of Defense," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-9*, June 1971, 118 pp.

[119] "U.S. Metric Study Interim Report: A History of the Metric System Controversy in the United States," U.S. Metric Study, Daniel V. De Simone, Director, Charles F. Treat, Historian, *NBS Special Publication 345-10*, August 1971, 298 pp.

4. Metrification for the United States is inevitable; planning for it is only sensible.
5. The U.S. Constitution gives the Congress the power—never used—of fixing the standards of weights and measures.

- The arguments "against":

1. There is no particular need for America to change from customary units.
2. The disadvantages of metrification outweigh the advantages.
3. Few countries use the metric system exclusively.
4. Metrification would be impractical and costly.
5. Compulsory metrification in the United States would be repugnant to American ideals.

A Metric Study task force on Engineering Standards, headed by Robert Stiehler and including Gustave Shapiro, Robert Klein, Harry Stoub, Arthur Strang and Theodore Young, prepared its report as *NBS Special Publication 345-11.*[120] The authors drew attention to the importance of the measurement system for engineering standards to be used in manufacturing products whose sizes were based upon simple progressions of units, such as is the case for screw manufacture. They also pointed out the irrelevance of the measurement system for items—such as the manufacture of electrical plugs—in which the problem is simply to replicate a pattern. They also noted that the great multitude of engineering standards in existence prompted them to limit the scope of their study to nine areas; steel and non-ferrous metals, plastics, rubber, pipe and tubing, anti-friction bearings, threaded fasteners, electrical and electronic components and equipment, and building construction and materials. In surveying the standards in these areas—less than 1 % of the 60,000 or more engineering standards issued as national standards by private and government organizations in the United States—they found that engineering standards could be harmonized internationally without the United States changing to the metric system. On the other hand, full standardization of manufacture would require most countries to modify their engineering practices. They foresaw the eventual use of metric units in all international standards.

As noted earlier, Jeffrey V. Odom coordinated a series of seven National Metric Study Conferences. A report was prepared which summarized the views given by the various participating groups.[121] Of the 700-odd groups invited to participate, about 230—representing 674,000 firms and more than 19 million individuals—did so. Of the groups expressing a preference for or against metrification, a strong majority found metrification to be inevitable and/or desirable. Most preferred a program of metrification on a national, coordinated basis over a 5-15-year span of time. Many industrial groups testified that the costs would be heaviest in inventory, new tools, re-training, and re-design. Consumers mostly agreed that metric conversion would be beneficial in the long run because of the simpler nature of the metric system, but that a long-term educational program would be required to make the transition successful.

[120] "U.S. Metric Study Interim Report: Engineering Standards," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-11*, July 1971, 250 pp.

[121] "U.S. Metric Study Interim Report: Testimony of Nationally Representative Groups," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-12*, July 1971, 165 pp.

Results of the Bureau's Metric Study

The viewpoint on metrification of the majority of participating individuals—both from within and outside NBS—came clear in the title of the Metric Study concluding report: "*A Metric America: A decision whose time has come.*"[122] Written by Metric Study Director De Simone, the summary contained a review of the metric debate, the implications of metrification for America, and a synopsis of the experience of Japan and the United Kingdom as they entered the metric world. De Simone stated the majority view forcefully:

> The U.S. Metric Study concludes that eventually the United States will join the rest of the world in the use of the metric system as the predominant common language of measurement. Rather than drifting to metric with no national plan to help the sectors of our society and guide our relationships abroad, a carefully planned transition in which all sectors participate voluntarily is preferable. The change will not come quickly, nor will it be without difficulty; but Americans working cooperatively can resolve this question once and for all.

In a one-page transmittal preface, Secretary Maurice H. Stans similarly urged the Congress to act. As requested by Congress, he offered his own recommendations. There were nine:

- That the United States adopt the metric system.
- That this step be accomplished through a coordinated national program.
- That Congress assign responsibility for guidance in metrification to a central body.
- That all sectors of the United States work out guidelines and timetables for metrification.
- That metric education of students be given high priority.
- That Congress immediately take steps to foster participation in international standards activities.
- That costs of metrification should "lie where they fall," to minimize costs of the program.
- That Congress should set a ten-year target date for effective completion of the metrification program.
- That there be a firm government commitment to this goal.

Because of the enthusiasm for metrification displayed by so many American organizations during the Metric Study, the Bureau staff was convinced that Congress would act quickly on Secretary Stans' recommendations. *The NBS Technical News Bulletin*

[122] "A Metric America: A decision whose time has come," Daniel V. De Simone, Director, U.S. Metric Study, *NBS Special Publication 345*, July 1971, 170 pp.

of September 1971 featured an eight-page summary of the reports in the *Special Publication 345* series. [123] A similarly extensive article appeared in the employee bulletin The NBS Standard. [124] Director Branscomb weighed in with supportive statements and articles. [125] Curiously, Secretary Stans' report was not buttressed by publicity from the White House—perhaps because the study revealed vocal, though minority, opposition to metrification among Americans who expressed themselves on the topic.

Controversy and Inaction

The ball was now clearly in Congress' court. It had to digest the thousands of pages of testimony contained in the reports and to make its own evaluation of the mood of its constituents with respect to metrification. Quickly the legislators learned that, as usual, those citizens who opposed the change were as vocal as those who favored it—sometimes more so.

To the surprise of many at NBS, some four years would pass before anything resembling a Congressional consensus would emerge. In the meantime, the Bureau opened a Metric Information Office to answer questions and to provide metric instruction to all comers. The office functioned for several years, distributing some 100,000 metric conversion kits by the end of 1975 and answering more than 20,000 letter requests for information during 1975 alone.

Despite all the evidence of public interest in metrification, the larger portion of the body politic held decidedly mixed views on the topic. Indeed, antipathy towards metric highway signs and metric weather reports was widespread. [126] And the efforts of labor and small businesses were mostly confined to assuring that any conversion costs for their constituents would be compensated by any metric legislation. Because of the divided opinion among its constituents, the 94th Congress passed a Metric Conversion Act of 1975 (PL 94-168) that contained encouraging words, but no substantial progress towards a metric America.

Following their fast-paced efforts, the Bureau members of the Metric Study team mostly returned to projects left undone. De Simone, the Study Director, could be found in January 1972 back at the Office of Invention and Innovation; the Metric Study section that had formerly been part of his office was disbanded.

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[123] "A Metric America," *NBS Technical News Bulletin*, September 1971, pp. 222-230.

[124] "Secretary Stans recommends metric conversion over 10-year period", *NBS Standard* Vol XVI, No. 8, August 1971, pp. 1, 12-15.

[125] One such, addressed to educators, a key sector in the anticipated program, was presented at the 1971 convention of the National Science Teachers Association. It was reprinted later as a handout: "The U.S. Metric Study," Lewis M. Branscomb, *The Science Teacher*, Vol. **38**, No. 8, November 1971, 5 pp.

[126] A well-written survey of post-metric-study responses was published by Edith F. Cooper, "The Metric Conversion Act of 1975; Legislative History and Implementation 1970-1980," *Report 10-203 SPR*, Congressional Research Service, Library of Congress, October 24, 1980.

As part of its continued effort to promote the use of the metric system in the United States, the National Bureau of Standards placed an interactive "Think Metric" exhibit in the lobby of its Administration Building in 1975. Groups of school children from Gaithersburg, Maryland, attended the exhibit.

Metrification—An Epilogue

Sent forth by Congress to gather data on the usefulness of the metric system to America and on the willingness of U.S. citizens to accept measurement units unfamiliar to them, the Bureau labored fiercely and delivered the requested information. The many conferences, interviews, and statements showed the rationality and value of the system, as well as the vocal feelings that existed on both sides of the question of the adoption of the metric system as a national policy. Little remained to be said. Daniel De Simone was honored as one of 10 top Federal employees by the National Civil Service League later during 1972. The National Conference of Standards Laboratories presented him with its Career Service Award. Soon, he was asked to join the office of the President's Science Advisor; he left NBS to do so. [127]

[127] *NBS Technical News Bulletin* May 1972, p. 116.

During the 1975 NBS "Think Metric" program, a student learned how much he weighed in kilograms.

Uncontrolled Fire, a Continuing Problem

As Lewis Branscomb assumed command of NBS, he, like his predecessors, was compelled to address the problem of loss of American life and property by the ravages of fire. Accidental fires in homes, offices, hotels, stores, factories, forests, and grasslands still claimed a disproportionate share of lives and goods. Fire had become a weapon of choice for rioters—the Watts area of Los Angeles had burned in 1965 and, two years later, rioters burned parts of Newark, New Jersey, and Detroit, Michigan, then attacked firemen who responded to the emergency calls. A Department of Labor occupational survey that year found fire-fighting to be the most hazardous of U.S. occupations. And one of the most visible fire tragedies ever seen had taken place on January 27, 1967, when a flash fire aboard the spacecraft Apollo killed astronauts Virgil I. Grissom, Edward H. White, II, and Roger B. Chaffee. The men were participating in routine testing prior to their anticipated first Apollo mission. Their deaths shocked the nation.

President Johnson addressed the growing menace of fire by requesting in 1967 that Congress consider fire safety legislation; bicameral responses took the form of extending the coverage of the *Flammable Fabrics Act* and hearings on a Fire Research and Safety Act. Both pieces of legislation assigned responsibilities to the National Bureau of Standards.

Flammable Fabrics, a Perennial Issue

NBS showed concern for flammable fabrics almost from its founding, no doubt in direct response to publicized fire disasters. [128] Fabric industry representatives, as might be expected, were of two minds on the topic: on the one hand, the magic of chemistry could produce cloth with wonderful properties such as colorfastness, strength, and warmth—though with an alarming tendency to flare at the touch of a match. On the other hand, it was clearly in their long-term interest to reduce the flammability of cloth. After World War II, the growing importation of foreign textiles without regard to flammability tipped the scales towards development of standards for burn-resistance.

Congress passed a Flammable Fabrics Act in 1953, in response to a growing number of tragic deaths of children and adults from burns incurred while wearing cowboy outfits, nightwear, scarves, and other items of clothing that easily caught fire. [129] This act gave particular responsibilities to NBS, including the development of a standard flammability test: any fabric that burned faster than a specified rate in the test could not be marketed in interstate commerce.

The 1953 act provided needed publicity to convince the clothing industry that flammability must be taken seriously. As such, it was a good start on the problem. But the one test method prescribed in the act was flawed. Further action was necessary if non-clothing types of fabrics were to be tested for fire safety.

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[128] G. M. Kline, "Fire-resistant doped fabric for aircraft," *J. Res. NBS* **14**, 575 (1935). See also Anonymous, "Flameproofing of textiles," *NBS Letter Circular LC467,* May 5, 1936, 9 pp. See also Marjorie W. Sandholzer, "Flameproofing of textiles," *NBS Circular C455,* August, 1946. The author notes loss of life in a Boston nightclub fire and a Hartford circus tent fire as reasons to pursue her study.

[129] Daniel Gross, "Fire research at NBS; the first 75 years," Invited lecture at the *Third International Symposium; Fire Safety Science,* pp. 119-133, 1989.

In the early 1970s, the fire research staff of the National Bureau of Standards developed test methods for the evaluation of flammability in children's sleepwear.

Flammable Fabrics Act, Amendment of 1967, (Public Law 90-189, 81 Stat. 568-574, December 1967)

In 1967, Congress extended the provisions of the 1953 Flammable Fabrics Act, directing the Secretary of Commerce, among other duties, to:

- Conduct research into the flammability of products, fabrics, and materials.
- Conduct feasibility studies on reduction of flammability of products, fabrics, and materials.
- Develop flammability test methods and testing devices.
- Offer appropriate training in the use of flammability test methods and testing devices.

Secretary Smith, as expected,[130] delegated these responsibilities to NBS. [131] However, Congressional funding for the program was not forthcoming until Fiscal 1969 (during October 1968), delaying implementation of the work for a full year. Even then, the funds amounted only to $304,000, barely enough to begin the new program. [132]

By the end of 1969, NBS had 17 staff members working full-time on the flammable-fabrics problems and several others working part-time. Three contracts had been let to outside research organizations to perform complementary tasks. The Bureau program was established in the Product Evaluation Division. James V. Ryan was named chief of the Flammable Fabrics Section, but soon he left NBS. Ryan was succeeded on a temporary basis by Sanford B. Newman. In 1969, new NBS Director Branscomb created within the Institute for Applied Technology an Office of Flammable Fabrics, temporarily headed by Elio Passaglia. In 1970, Joseph E. Clark was appointed permanent head of that Office.

Initial flammable-fabrics projects at NBS included determination of the products of fabric combustion, calorimetry of fabric combustion, laboratory burning of fabrics, analysis of burn cases, study of flame retardants, instrumented burning of full-scale household furnishings, and study of heat transfer from burning fabrics. Outside contractors studied the burning of carpets and rugs, and the preparation of sampling questionnaires. A symposium on the measurement of flammability was held in Washington, DC on June 5-6, 1969; more than 600 people attended the meeting to learn details of the new program. Further publicity came from notices placed in the *Federal Register.* [133]

During 1970, flammability standards were established for two types of carpets and rugs, and another was proposed for children's sleep-wear. Conflicting test methods and the uncertainty that was necessarily involved in developing sampling techniques complicated the NBS efforts. In the same year, testing was begun on mattresses and blankets, building on work accomplished during earlier years. [134]

Besides effort expended specifically on developing test methods to evaluate the flammability of carpets and rugs, children's sleep-wear, and blankets and mattresses, the Office of Flammable Fabrics sponsored a number of research projects. Some of

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[130] Allen Astin had held preparatory meetings with the Public Health Service. See Memo, AV Astin to Secretary, "Implementation of Amended Flammable Fabrics Act," May 27, 1968; RHA; Dir. Off. ; Box 386; Chron Folder May 1968.

[131] Department Organization Order 30-2A, October 1, 1968.

[132] AV Astin, "Chronology of Activities and Implementation of Revised Flammable Fabrics Act," February 8, 1969; RHA; Dir. Off. ; Box 388; Chron. Folder February 1969.

[133] Material from *NBS Technical Note 525*, "The Flammable Fabrics Program, 1968-1969," April 1970, 76 pp.

[134] Material from *NBS Technical Note 596*, "The Flammable Fabrics Program, 1970," September 1971, 56 pp.

these were accomplished within NBS and others were performed by outside groups under contract to the Bureau. Projects included:

- Identification of fabric combustion products.[135]
- Calorimetry—measurement of the heat produced by burning fabrics.
- Full-scale burn experiments, intended to identify all the hazards that accompanied fires involving carpets or upholstered furniture.
- Heat transfer between burning fabrics and the human body (performed at the Cornell University Aeronautical Laboratory).

NBS work on flammable fabrics decreased dramatically with passage of the *Consumer Product Safety Commission Act* (Public Law 92-573, October 27, 1972). Congress transferred to the CPSC all responsibility for continuing to implement the Flammable Fabrics Act. The Bureau role changed to providing technical support to CPSC within the context of its regular fire program.

Viewed in retrospect, participation in a program so near to regulatory responsibility was somewhat removed from the Bureau's most comfortable role. In fact, the responsibilities of the Secretary of Commerce were not entirely clear; the language of the *Flammable Fabrics Act* caused the Secretary to suggest that standards "might be needed," leaving any decision open to criticism. Nevertheless, the publicity attending the creation of the Act and the establishment of the CPSC—not to mention the standards that actually came to fruition—provided powerful incentives to the fabric industry to reduce the chances of death or economic loss from use of their products.

Fire Research and Safety Act of 1968 PL90-259

Responding to the call by President Johnson in 1967 for renewed legislative attack on the problem of uncontrolled fire, the 90th Congress amended the NBS Organic Act and authorized a new program in fire research through the *Fire Research and Safety Act of 1968.*

Governmental efforts to shore up the Nation's beleaguered fire-prevention and fire-fighting units had been mostly scattered and ineffectual up to that time. In 1961, a panel formed by the National Research Council of the National Academy of Sciences had recommended that a Federal center be created to focus on the problem of uncontrolled fire. NBS subsequently was designated a central agency for fire research, in recognition of its long-standing and effective work in the field, by the Federal Council for Science and Technology.

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[135] One of these was undertaken by Robert J. McCarter, who developed an apparatus to be used in measuring the rate at which vapors were evolved during thermal degradation. See R. J. McCarter, "Apparatus for rate studies of vapor-producing reactions," *Proc. Symp. on Current Status on Thermal Analysis, NBS Gaithersburg, April 20-21, 1970*, SP 338, October 1970, pp. 137-150.

Seeking substantial funding to establish a new fire program in fiscal year 1964, the Bureau had found itself in the center of a controversy which never seemed to die out.[136]

The NBS fire plan was threefold: to begin an educational effort to better inform the American public about the dangers of fire and ways to reduce its likelihood; to assist in university-level training in fire studies; and to bolster and focus its own fire-research program. The International Association of Fire Chiefs was enthusiastic about the Bureau's plan, but the National Fire Protection Association, fire insurers, and other industrial representatives were critical. Predictably, no funds were forthcoming that year.

By 1965, accidental fires cost more than 12,000 lives each year in the United States, and more than $1.5 billion in property loss. Publicity surrounding the very visible fire losses in the period 1965-67 finally prompted both the President and the Congress to action.

PL90-259, enacted into law on March 3, 1968, assigned to the Secretary of Commerce in its Title I many features of the earlier NBS plan—"provide a national fire research and safety program, including the gathering of comprehensive fire data; a comprehensive fire research program; fire-safety education and training programs; and demonstrations of new approaches and improvements in fire prevention and control, and reduction of death, personal injury, and property damage." The secretary was directed to establish a fire center to focus these many activities.

Title II of the new act established a National Commission on Fire Prevention and Control. Its 20 members were to furnish in two years a report to Congress with recommendations on methods for the abatement of fire losses.

Given the extensive publicity surrounding the Nation's fire problems and the care with which assignments were given under its provisions, it is astounding that no funding was immediately provided by the Congress to implement the Fire Research and Safety Act of 1968. To understand its lack of support for its own creation, one must remember the dichotomy that is Congress; one committee authorizes work, another committee appropriates funds to implement it. The affected agency—in this case, the National Bureau of Standards—can be left holding the bag.

Lacking essential funding, Bureau management did what it could to satisfy the intent of the 1968 act; it created an Office of Fire Research and Safety in the Institute for Applied Technology, and assigned John A. Rockett as its head. This office was deliberately placed outside the Building Research Division, home to the Fire Research Section. The section was headed at that time by Irwin A. Benjamin. An example of useful work done during that time was a pilot study by James O. Bryson and Daniel Gross; they surveyed two large office buildings, evaluating live floor loads and fire loads. The results were utilized by the American Iron and Steel Institute as the basis for statistical sampling in other buildings.[137]

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[136] Appropriation hearings, FY 1964, pp. 978-980.

[137] J. O. Bryson and D. Gross, "Techniques for the survey and evaluation of live floor loads and fire loads in modern office buildings," *Building Science Series*, No. 16, 312 pp. (1969).

With the collaboration of Alexander F. Robertson, Rockett planned the future of the NBS fire program, which now could include the investigation of accidental fires, the accumulation of fire statistics on a national basis, the development of fire-prevention and fire-control measures, and training and education activities to complement Benjamin's program.

And in 1972, the Bureau created an Office of Fire Programs under the leadership of G. King Walters; the Office of Flammable Fabrics, established in 1970, was placed under Walters as well. When Walters left NBS later that year, an NBS Fire Technology Division was created with Joseph E. Clark as Chief.

The 1968 act did not accomplish its major objectives, but it set a new and expanded course for the Bureau's fire program.

An Experiment in Technology Incentives Is Proposed

In August 1971 (see **The NBS Budget**, p. 182), President Richard Nixon responded to an increasingly sick U.S. economy by unveiling a *New Economic Policy.* Some of the provisions of the new policy—calling for reduced Federal expenditures and reduced Federal employment levels—were costly to the Bureau both in personnel and in funds. However, one feature that evolved early in 1972 from the plan was intended to establish at NBS a new multi-million-dollar project designed to boost the use of modern technology in American industry.

Because of the timing of the New Economic Policy, nearly a year would pass before Congressional funding would be requested for its execution.[138] By the time funds became available for the Bureau's part in the new proposal, NBS had a new director. We note here the birth of the new program because it foretells so clearly the movement towards direct NBS involvement in the problems of American industrial productivity, a movement that eventually would rename NBS.

The unusual circumstances under which the program originated were outlined earlier in this chapter. In essence, NBS was asked to explore various ways in which incentives could be placed before industry to encourage the use of newer technology, with the expected result that American industry would become more competitive in both domestic and international trade.[139] The name for the project, the *Experimental Technology Incentives Program* (ETIP), was selected more or less on the spur of the moment,[140] in order to meet a deadline for completion of a budget document early in 1972.

Although the ETIP name was chosen somewhat arbitrarily, the concept behind it rested solidly on work performed late in 1971 for the Office of the Assistant Secretary of Commerce for Science and Technology by a study team from the Bureau's Technical Analysis Division.

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[138] The first presentation on the president's experimental technology plan was made to the House Appropriations subcommittee by Lewis Branscomb at the Fiscal 1973 budget hearing, March 1972.

[139] Memo, L. Kushner to L. Branscomb, January 26, 1972; RHA; RG 167; Director's Office; Box 424; Folder January 1972.

[140] Lawrence Kushner, Oral History, June 7, 1988.

Under the guidance of John A. Birch, Advisor for International Affairs for the Department of Commerce, the NBS team reviewed efforts in five countries to stimulate invention and innovation and the development, transfer, and application of new technologies within their own industries. Behind the review was the hope that it could lead the U.S. government to policies that would reverse the decline in its balance of trade and enhance the development and export of high-technology products.

The study was directed by George C. Nichols, Senior Economist of NBS, who examined the principal technology enhancement programs, mechanisms, and incentives used in the civilian sector of Japan. The same pattern was followed by Suellen Halpin for Canada, Donald W. Corrigan for France, John C. Schleter for Germany, and Stephen S. Karp for the United Kingdom.

The Bureau team learned that the countries with well defined science and technology goals appeared to be more successful in stimulating technological advances within their industrial sectors. They also found:

- The most effective technology enhancement programs came from Science and Technology agencies placed at the highest levels of government.
- An atmosphere of trust and open communication between government and the private sector was essential.
- Successful technology enhancement involved continual modernization of equipment and facilities, spurred by government policies and incentives.
- Special attention to the needs of small- and medium-sized firms was beneficial.
- Extra funding accompanied by extra government interference and "red tape" was not especially helpful in technology enhancement.

Not until December 1972 was a report describing the results of the study made available to the public, and even then the release took the form of an internal Department of Commerce document rather than an NBS publication.[141] Nevertheless, the clarity of the study results moved the department to initiate multi-million-dollar funding for an NBS technology enhancement program in March 1972 so that work could begin in Fiscal 1973.

The Bureau scrambled to flesh out the basis for what would become—Congress willing—a substantial NBS undertaking.[142] Quickly, Director Branscomb assigned to Edwin J. Istvan, newly employed by the Center for Computer Science and Technology, leadership of a Bureau "ETIP team."[143] In preparing the ETIP concept, Istvan and his

[141] "Technology enhancement programs in five foreign countries", Walter G. Leight, editor, DoC Report COM-72-11412, December 1972, 328 pp. Section authors: Suellen Halpin, Donald W. Corrigan, John C. Schleter, George C. Nichols, Stephen S. Karp. Project Director: George C. Nichols. General Advisor: John A. Birch.

[142] Memo, L Branscomb to Larry Jobe, Asst. Sec. of Comm. for Administration, January 28, 1972; RHA; RG 167; Director's Office; Box 424; Folder January 1972.

[143] Memo, L Branscomb to NBS Executive Board, February 4, 1972; RHA; RG 167; Director's Office; Box 424; Folder February 1972.

team made a serious effort to involve private industry. Acting quickly and using methods reminiscent of the Metric Study, they contacted a large number of individuals and corporations:

- All of the members of NBS Evaluation Panels (300 individuals).
- The 20-member Inventors' Council.
- Thirty trade associations.
- Senior officials at more than 100 corporations, 8 universities, 7 professional societies, and 18 research institutes.
- Government officials in two states, 7 local government associations, and 11 departments.

The persons contacted were queried about their response to the ETIP idea, whether their organizations might by willing to participate, and the types of activities that seemed most attractive. The responses were uniformly positive.[144]

The results of Istvan's efforts quickly appeared in the March 1972 House hearings on the fiscal 1973 Bureau budget, where Branscomb described a $14.4 million program:[145]

> In partnership with the private sector, NBS will test the usefulness of various mechanisms and incentives to stimulate the generation and application of private research and development in ways that permit the private sector to further the Nation's productive capacity, industrial competitiveness, and our national well being. The end product of this program is a better understanding of these mechanisms and incentives.

In the final NBS budget for fiscal 1973, the ETIP program was allocated $10 million. This handsome sum was immediately reduced to $6.2 million as an economy measure by President Nixon. However, the task of choosing a leader who would spend the money and produce results fell not to Lewis Branscomb, but to his successor. More about ETIP later.

A New Building for Fluid Mechanics Studies

During 1969 the twentieth major building for the Gaithersburg site was completed and occupied. It was dedicated to the study of fluid mechanics; several special facilities were included in the design to make the new laboratory one of the finest anywhere.

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[144] Memo from LMB to the Under Secretary of Commerce, March 10, 1972: "Activities Related to the Proposed NBS Experimental Technology Incentives Program." RHA; RG 167; Director's Office Box 424; Folder-Chrono, March 1-31, 1972.

[145] House Hearings for Fiscal 1973 (March 28, 1972), pp. 1085-86.

One large laboratory featured facilities for calibration and research in large air meters and water meters. It was designed to aid NBS in developing and applying improved flow-rate measurements, transfer standards and flow theory. Dried, filtered air was available at flow rates from 45 grams to 2 kilograms per second. Treated water could be pumped from a quarter-million-liter reservoir at a rate of 40,000 liters per minute. Low-level flows could be metered within a temperature-controlled environment, and special facilities were available for monitoring flow of hydrocarbons, including jet fuel.

Also included was an aerodynamics laboratory which permitted study of both laminar and turbulent air flow at speeds that ranged into the supersonic area. Wind-speed instruments could be calibrated in the range 2-150 mph. Boundary-layer studies were contemplated, as well as wakes and jets. A subsonic and a supersonic wind tunnel were both made part of this facility. A portion of the subsonic tunnel walls could be moved in order to vary the internal pressure distribution.

A water tunnel was built as part of the hydraulics section of the new building, as was a 1-meter square, 13-meter long wave tank.

The new building took NBS to the forefront of yet another technical field.

Science in Outer Space

Bureau scientists contributed in many ways to the successes of America's space program and to astronomy. In projects as varied as providing calibration of the mighty rockets used to lift spacecraft from their earthly bonds, measurement of the distance from earth to the moon, and the study of the sun's radiation, information and instruments from NBS lifted man a step closer to the stars.

In this section we summarize a few projects that illustrate Bureau contributions to space science during the directorship of Lewis Branscomb.

Lunar Ranging

On July 21, 1969, astronauts Neil A. Armstrong and Edwin W. "Buzz" Aldrin, Jr. carefully placed an aluminum panel the size of a generous birthday cake—46 cm square—on the surface of the moon, tilting it a bit so that it pointed towards the earth. In doing so, the astronauts initiated an experiment in lunar ranging, one in which NBS scientists played a pivotal role.

The aluminum panel, said the report, describing the experiment, contained an array of 100 "corner-cube" retro-reflectors:

> . . . made by cutting a nearly perfect cube of fused silica in half across a body diagonal, then polishing the resulting new face flat. Light entering the new face has the interesting and useful property that it is reflected from the three mutually perpendicular faces of the rear corner, returning along the same direction from which it came. [146]

[146] Slightly paraphrased quote from P. L. Bender, D. G. Currie, R. H. Dicke, D. H. Eckhardt, J. E. Faller, W. M. Kaula, J. D. Mulholland, H. H. Plotkin, S. K. Poultney, E. C. Silverberg, D. T. Wilkinson, J. G. Williams, and C. O. Alley, "The lunar ranging experiment," *Science* **182**, No. 4109, pp. 239-238, October 19, 1973.

Q-switched ruby lasers, installed at two earth-bound observatories, soon began sending pulses of light in the direction of the retro-reflectors in the hope of measuring several quantities, among them the distance between earth and the moon. If the experiment worked, it could substantially reduce the uncertainty in the earth-moon separation below previous estimates of ± 500 m.

The lunar-ranging project was the brainchild of a group of physicists from several institutions, allied with scientists working on the NASA Apollo missions. The project leader was C. O. Alley of the University of Maryland. Co-investigators included Peter L. Bender of the Bureau's Joint Institute for Laboratory Astrophysics (JILA); R. H. Dicke and D. T. Wilkinson of Princeton University; James E. Faller, then of Wesleyan University but by 1972 a JILA staff member; W. M. Kaula of the University of California at Los Angeles; G. J. F. MacDonald of the University of California at Santa Barbara; J. D. Mulholland of the Jet Propulsion Laboratory at the California Institute of Technology; and H. H. Plotkin of the NASA Goddard Space Flight Center. W. Carrion of NASA Goddard and R. F. Chang, D. G. Currie, and S. K. Poultney of the University of Maryland also participated in the work.[147]

The idea behind lunar ranging was simple: shine light on the moon for a moment and measure the time taken for the pulse of light to return.[148] But it took a decade of work for the idea, once undertaken by the group, to reach fruition. A key ingredient was the use of retro-reflectors. Attempts to perform the measurement using laser-light reflections from the lunar surface itself suffered from uncertainties created by the moon's curvature and its poor reflectivity, but use of the corner-cube array sharpened the return pulse and increased its intensity by 10 to 100 times.

Another major problem was placing the reflector unit on the moon. The unit as designed could be deployed automatically; by 1968, however, the NASA unmanned Surveyor program was complete. Furthermore, the Apollo Lunar Surface Experiments Packages for each of the manned lunar landings were already committed to other experiments. The ranging team got lucky, however, when the Apollo 11 managers decided to replace a heavier, more complex experiment with the lightweight, easily deployed, rugged, and scientifically important Lunar Ranging Experiment (LRE).

Telescopes at two astronomical observatories, the 3. 0 m (120 in) instrument at the Lick Observatory on Mount Hamilton in California and the 2. 7 m (107 in) telescope at the McDonald Observatory at Fort Davis in Texas, were equipped with ruby lasers,

[147] C. O. Alley, R. F. Chang, D. G. Currie, S. K. Poultney, P. L. Bender, R. H. Dicke, D. T. Wilkinson, James E. Faller, W. M. Kaula, G. J. F. MacDonald, J. D. Mulholland, H. H. Plotkin, W. Carrion, and E. J. Wampler, "Laser ranging retro-reflector: Continuing measurements and expected results," *Science* **167**, January 30, 1970, 458-460 (1970).

[148] Galileo had tried to perform the converse of this experiment centuries earlier—determining the speed of light by measuring the time that elapsed between his uncovering a lantern and his observation of light from the lantern of an assistant who was standing a measured distance away and who was instructed to uncover his lantern at the first glimpse of light from Galileo's lantern. The delay time involved in human response, of course, proved far longer than the travel time of light between the earth-bound lantern stations.

which could deliver pulses of light of about 3 ns half-width at a wavelength of 694 nm and an intensity of 7 joules per pulse. Since the round-trip travel time from earth to the moon was approximately 2.5 s, the laser firing rate could be set at 3 s, allowing for many pulses—and therefore good statistical averaging—in a relatively short time interval. The LRE team expected that measurements could be accomplished during the lunar day as well as the night, providing only that the moon was sufficiently high in earth's sky to permit good viewing.

The lunar ranging experiment had to be fitted into a full schedule of astronomical work in both observatories. Therefore a schedule was set of 50-200 pulses per attempt, with three attempts per day, permitting considerable improvement in results through signal-averaging without monopolizing the telescopes.

Despite considerable effort to collimate the laser beam as it passed through the observing telescope, it was expected that the laser light would diverge to cover an area on the moon 4-6 km in diameter, reducing the return signal to about 1 photon per laser pulse. However, careful screening of spurious light and electronic time-sorting of the return signals could make even such sparse results meaningful.

Excruciating delays—due to moon position in the sky, bad weather, and earthly equipment problems—followed the July 21st deployment of the reflectors by astronauts Aldrin and Armstrong. On the first of August, though, return signals were obtained by the Lick observatory telescope, then by the McDonald instrument as well.

Early results indicated a ranging uncertainty below 10 m, a substantial improvement over previous determinations. The imprecision of the measurements quickly dropped to ±0.3 m, with further improvement expected. The Lunar Ranging Experiment was a success.

Encouraged by the quality of the Apollo 11 experiment, NASA happily scheduled the deployment of a similar retro-reflector array by Apollo 14. It was placed on the moon on February 5, 1971; return signals were obtained the same day. A larger package containing 300 reflectors was carried on the Apollo 15 flight and deployed on July 31, 1971. Besides the NASA units, retro-reflectors built in France were carried to the moon by the Soviet spacecraft Luna 17 in November 1970, and Luna 21 in January 1973; the McDonald Observatory obtained signals from the latter within days of its deployment.

By mid-1971, enough ranging data had been obtained to permit an evaluation and possible correction of the moon's orbit. It was expected that observations from more than one earth site would also permit the detection of tectonic motion on the earth's surface.

In 1976, James Faller completed construction of a telescope that was designed specifically for the lunar-ranging studies. [149] Composed of 80 lenses, each with its own system of mirrors to focus light on a single point on the telescope axis, the instrument—with its large aperture and tiny field of view—made optimum use of the tenuous beam returned from the moon's retro-reflectors.

[149] This part of the lunar-ranging story was summarized well by Bragaw and Snyder, op. cit., pp. 638-670. The telescope was described in clear terms in articles by Frederick P. McGehan, "The fly's eye telescope," *NBS Dimensions* **62**, pp. 3-6 (1978), and David Orr, "A technical look at the telescope," *NBS Dimensions* **62**, pp. 6-7 (1978).

The telescope was built with a light but extremely rigid body, so that it could be pointed automatically in any celestial direction, using computed lunar ephemeris data. Its output signal was handled in a manner similar to that of its larger astronomical cousins at the Lick and McDonald observatories. During August 1976, the telescope was placed on Mount Haleakala in Hawaii, which rides on the Pacific tectonic plate. From this installation arose the possibility of utilizing lunar ranging to directly detect movement between the Pacific plate and the continental United States plate.

In a later paper written for the journal Science, Faller, Bender, and their colleagues summarized the many contributions to man's knowledge of the earth-moon system brought by the Lunar Ranging program:[150]

> Lunar laser ranging turns the earth-moon system into a laboratory for a broad range of investigations, including astronomy, lunar science, gravitational physics, geodesy, and geodynamics.
>
> Contributions from lunar laser ranging include a three-orders-of-magnitude improvement in accuracy [to ±3 cm] in the lunar ephemeris, a several-orders-of-magnitude improvement in the measurement of the variations in the moon's rotation, and the verification of the principle of equivalence for massive bodies with unprecedented accuracy. Lunar laser ranging analysis has provided measurements of the earth's precession, the moon's tidal acceleration, and lunar rotational dissipation.

Coupled with other studies such as Very Long Baseline Interferometry, lunar ranging helped to refine the picture of the earth and the moon as liquid-filled, undulating plastic spheroids, eternally coupled by gravitational forces as they whirl in their orbits about the sun. The sets of retro-reflectors installed on the surface of the moon by the Apollo astronauts still operated normally after 25 years. Returning to earth only 10^{-21} of the light sent their way from 385,000 kilometers distance, the simple devices greatly enriched man's understanding of his nearby universe.

Stellar Atmospheres

Bureau scientists at the Joint Institute for Laboratory Astrophysics, in collaboration with colleagues at several universities, made substantial contributions to the understanding of stellar atmospheres during this period:

- J. P. Cassinelli and David G. Hummer discussed stellar radiative transfer in terms applicable especially to spherically symmetric systems.[151]

[150] J. O. Dickey, P. L. Bender, J. E. Faller, X. X. Newhall, R. L. Ricklefs, J. G. Ries, P. J. Shelus, C. Veillet, A. L. Whipple, J. R. Wiant, J. G. Williams, and C. F. Yoder, "Lunar laser ranging: A continuing legacy of the Apollo program," *Science* **265**, pp. 482-490 July 22, 1994.

[151] J. P. Cassinelli and D. G. Hummer, "Radiative transfer in spherically symmetric systems: II. The non-conservative case and linearly polarized radiation," *Monthly Notices of the Royal Astron. Soc.* **154**, No. 1, 9-21 (1971).

- A discussion of spectrum formation in stars with extended atmospheres, held during a colloquium of the International Astronomical Union, featured a paper by Richard N. Thomas that focused attention on the significance of the ideas behind the "extended stellar atmosphere."[152]

- Katharine B. Gebbie edited the proceedings of a symposium, held to honor the 70th birthday of astronomer Donald H. Menzel, on the topics of solar physics, atomic spectra, and gaseous nebulae. Professor Menzel contributed much to the success of the astrophysics program at the Bureau.[153]

- A strong disagreement between theory and experiment was resolved in favor of experiment at the Joint Institute for Laboratory Astrophysics. New experimental cross-sections for the photodissociation of the positive ions of hydrogen and deuterium, species important to astrophysics, were determined at wavelengths from 247 nm to 1.3 μm by Friedrich von Busch and Gordon H. Dunn of JILA.[154] Marked disagreement with earlier theoretical calculations, including some by Dunn himself, stimulated the project. The theory involved normalized Franck-Condon factors for the vibrational populations of the ions. Finding persistent disagreement between the theory and results obtained with the use of improved experimental conditions, the authors were led to the conclusion that the Franck-Condon approximation was not valid for the conditions they were studying.

Cryogenics in Space

Projects undertaken by the Cryogenics Division in Boulder had a significant impact on the U.S. space program. Division scientists and engineers provided data on the properties of cryogenic materials, they performed engineering calculations, and they served as consultants both to the National Aeronautics and Space Administration and to its contractors.

Among these projects were:

- Thermodynamic properties—equation-of-state, specific heat, sonic velocity, thermal conductivity, and viscosity—of hydrogen and oxygen used for propulsion, fuel cells, and breathing-oxygen systems.

- Measurements, engineering, and consultation for CENTAUR, the first hydrogen/oxygen-propelled vehicle, and for subsequent programs.

[152] R. N. Thomas, "Definition of the physical problems connected with extended atmospheres," *NBS Special Publication 332,* pp. 38-54 August 1970.

[153] "The Menzel symposium on solar physics, atomic spectra, and gaseous nebulae in honor of the contributions made by Donald H. Menzel," K. B. Gebbie, Editor, *NBS Special Publication 353,* 213 pp., August 1971.

[154] F. von Busch and G. H. Dunn, "Photodissociation of H_2^+ and D_2^+; Experiment," *Phys Rev.* **A 5**, No. 4, 1726-1743 (1972).

Another project involved study of partially frozen "slush" samples of hydrogen, methane and natural gas, and mixtures of the latter two substances. These materials possessed very high heats of combustion—higher than either gasoline or kerosene—and they burned "clean," making them prime candidates for fuels for high-performance aircraft, rockets, and other vehicles. Use of the cryogens in partially frozen form was certain to reduce evaporative losses during storage and transfer, provided that suitable techniques could be developed for handling and utilizing the mixed-phase materials.

D. H. Weitzel, Jose E. Cruz, L. T. Lowe, R. J. Richards, and Douglas B. Mann developed instrumentation to store and transfer hydrogen in both liquid and slush form. They also measured the densities of the materials and developed devices to measure flow of the cryogens. [155] Charles F. Sindt and Paul R. Ludtke performed similar work with respect to liquid and slush methane, natural gas, and various mixtures of the two.[156]

Aerospace Calibrations

The U.S. space program utilized many instruments at the limits of their capabilities. Communications, optical systems, thermometry, and mechanical measurements were examples of areas requiring careful calibration to ensure adequate performance.

The projects were accomplished mostly by "unsung heroes"—Bureau staff members whose work did not result in publications, but whose services were recognized by their customers as vital to reaching national goals. Evaluation and calibration services involved antenna standards; the quality of shielding for electromagnetic radiation; microwave and radar performance and noise measurements; load cells to measure the thrust of the huge rocket engines (see the discussion in the next section); aircraft fatigue measurements; mechanical properties of composites; high-temperature thermocouple thermometers; radiometers; vacuum ultraviolet radiation standards; and x-ray standards.[157]

Mentioned in Chapter 1 was the Interagency Transducer Project, which contributed heavily to the space program. During the period covered by this chapter, Electronic Technology Division personnel were asked to adapt the calibration of static pressure transducers to the measurement of pressure under non-static conditions. In some cases—particularly those involving large rocket engines—telemetry

[155] D. H. Weitzel, J. E. Cruz, L. T. Lowe, R. J. Richards, and D. B. Mann, "Instrumentation for storage and transfer of hydrogen slush," *Advances in Cryogenic Engineering* **16**, pp. 230-240 (1971). The work of these scientists and a colleague, Robert Arnett, was credited with materially assisting in the design of the Pratt and Whitney RL-10 "Centaur" spacecraft engine; see *NBS Standard,* Vol XV, No. 2, February, 1970, p. 7.

[156] C. F. Sindt and P. R. Ludtke, "Characteristics of slush and boiling methane and methane mixtures," *Proc. XIIIth Int. Congress of the International Institute of Refrigeration, Washington, DC, Aug. 27 - Sept. 3,* 1971, pp. 1-6.

[157] Much of the material in this section was suggested in a letter from Robert S. Walleigh to Donald C. Winner, NOAA, dated November 16, 1971; RHA; RG 167; Director's Office; Box 391; chron folder November 1971.

repeatedly showed pronounced spikes in the pressure signals during ignition of the enormous engines. Careful study by the Bureau group, including Paul S. Lederer, John S. Hilten, and Leon Horn, showed that the apparent pressure spikes were spurious. They arose as a result of severe temperature gradients across the transducer as the igniting fuel rapidly heated only one end of it.[158]

Force Testing on a Large Scale

The need for calibration of the large forces encountered in rocketry increased dramatically as America entered the space race. Knowledge of the weight of "big birds" and measurement of the thrust of huge rocket engines were vital to the success of NASA's extraterrestrial missions.

As late as 1961, the Bureau capability for such services, maintained within the Mechanics Division, was far behind NASA's needs. During the previous two decades, the demand for large-force calibrations from NBS had increased by more than a factor of twenty, and many of these requests could not be met at all by the Bureau's outmoded equipment.[159] NASA needed to determine the actual forces exerted by rocket engines designed to deliver more than one million pounds of thrust. The Bureau's biggest dead-weight tester, with a capacity of but 0.5 meganewtons (SI symbol MN; about 112,500 pounds of force), was no help for such a task.

To comprehend the concept of the forces involved in aerospace projects, it was important for the layman to understand the distinction between mass measurement and force measurement and the relation of these mechanical terms to the common noun "weight." Mass, one of the base units of measure in the International System of Units, was defined in terms of an artifact—a physical object. The unit of mass, one kilogram, was defined by a cylinder of platinum-iridium alloy retained by the International Bureau of Weights and Measures as the international prototype. In the study of elementary mechanics one found that force was equal to the product of mass times acceleration. "Weight," as the term was commonly used in America, actually referred to a force, not to a mass. Space travel, with its essentially zero-gravity environment, provided a vivid reminder of this difference. For example, the *weight* of a one-kilogram *mass* on the moon, where the magnitude of gravitational attraction was about one-sixth of its value on earth, would be only one-sixth of its weight on earth. And measured in the near-zero gravity of outer space, the same one-kilogram mass would become weightless (as the first astronauts quickly discovered), even though the mass of the object clearly would remain equal to one kilogram.

Another useful distinction relative to force measurement was the difference between calibration using sets of weights of various sizes to provide the reference force and calibration in which the magnitude of an unknown force was evaluated by the use of a force transducer—a proving ring or a load cell. The uncertainty of the former (more basic) calibration typically was smaller by a factor of ten than the latter.

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[158] John Franklin Mayo-Wells kindly supplied this information.

[159] Testimony of Allen Astin, House hearings May 3, 1961, p. 821.

The reason for the smaller uncertainty in calibrations involving weights sets lay in the tighter uncertainty budget. Uncertainties of only about 10^{-6} each were contributed for calibration of the masses used, for the correction for air buoyancy, and for the acceleration due to gravity at the site of the calibration.

Calibration by the use of weight sets was restricted to vertical tension or compression, whereas the force axis of hydraulic or other force-generating machines—often called Universal Testing Machines—could be placed in any direction.

In 1965, six new "deadweight" calibration installations were put in operation at NBS. Their capacity ratings in newtons (or pounds of force) were 2.2×10^3 (495), 2.7×10^4 (6,078), 1.13×10^5 (25,438), 5×10^5 (112, 559), 1.33×10^6 (300,000) and 4.45×10^6 (1,000,000). The largest of these provided a calibration uncertainty limited to 0.002 %—80 newtons or 20 pounds—in either tension or compression. More efficient design shortened by half the time required for testing, an important advance considering that some 1000 devices per year—including direct measurements for certain NASA space flights—were calibrated at that time. Temperature was controlled in the facility to minimize uncertainties from this source. Arnold J. Mallinger and Raymond Russell were among the staff members involved in the force calibrations.[160]

In 1970, the Bureau provided calibration services for three types of devices used to measure force:

- "Load cells"—devices for converting a force to a magnetic, frequency or electrical-resistance output.
- "Proving rings"—actual ring-shaped devices invented at NBS in 1926 by S. N. Petrenko, in which the deformation of the ring could be evaluated in terms of the applied force.
- "Elastic force measuring devices"—similar in principle to proving rings.

These devices could be calibrated in terms of compression, tension or both for forces ranging as high as 4.5 MN.[161]

In 1971, a new Universal Testing Machine was installed in the Engineering Mechanics building, replacing an older ten-million-pound-force compression tester. The new machine, using hydraulic force-generation, was capable of applying compression forces as large as 54 MN (about 12 million pounds). Three firms participated in its realization. It was designed by the Wiedemann Machine Company of Grove City, Pennsylvania; the E. W. Bliss Company of Salem, Ohio, manufactured the components; and assembly was accomplished by the McDowell-Wellman Company of Cleveland. The tester immediately became the largest such apparatus in the world.[162] Simply installing the machine was a challenge—it topped 33 meters in height including a 7-meter length underground. Tension tests up to 27 MN could be applied to specimens as long as 18 m, and 30 m long structural members could be tested for flexure using forces up to 16 MN.

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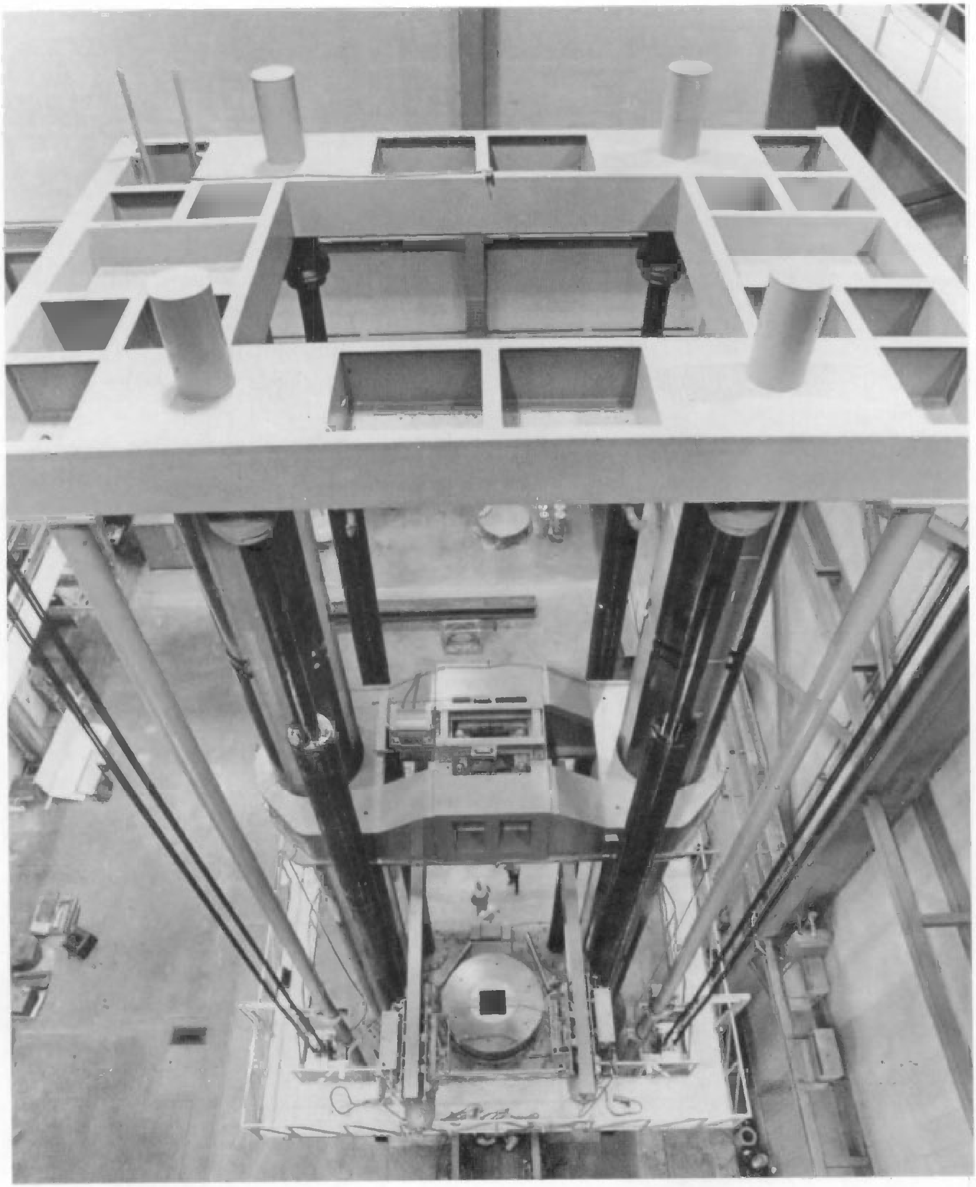
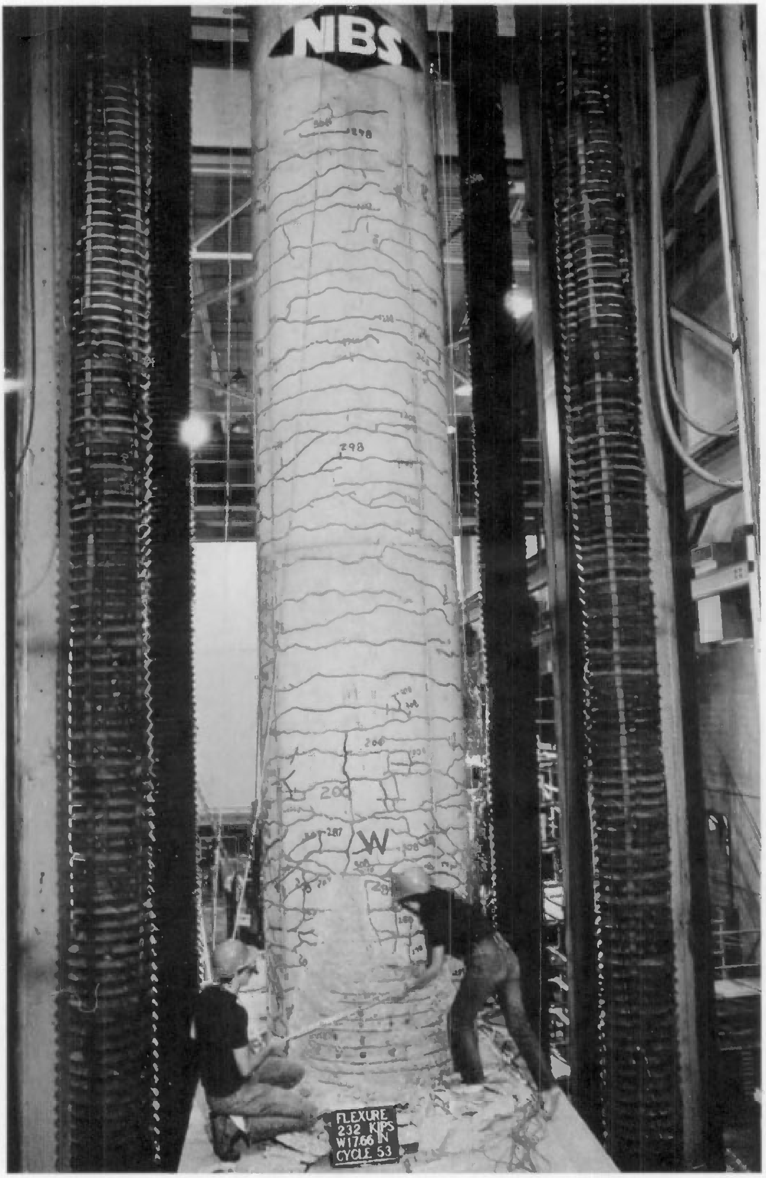
[160] "New NBS Force-Calibration Facilities," *NBS Technical News Bulletin*, November 1965, p. 186-188.

[161] "Calibration and Test Services of the National Bureau of Standards," *NBS Special Publication 250*, December 1970, pp. 4.5–4.8.

[162] "World's Largest Testing Machine Goes Into Operation," NBS Technical News Bulletin, November 1971, p. 274. See also "A gentle giant is dedicated," *NBS Standard* Vol XVI, No. 10, November 1971, p. 3.



Seen from above, the 12-million-pound-force Universal Testing Machine, installed in the Engineering Mechanics Building in 1971, dwarfed its operators.



Technicians examined a concrete column which was flexed to destruction by the Bureau's 12-million-pound-force Universal Testing Machine.

Mechanical Engineer Samuel R. Low stood on the platform of the NIST 12-million-pound-force Universal Testing Machine circa 1988. Behind him was the then-record fracture test specimen, a 35 ft long test specimen with a 6 in thick, 40 in wide insert. It took 5.94 million pounds of force in tension to fracture the insert.

Estimates of the force applied by the UTM were provided by several transducers. The load applied to the specimen was evaluated within about 0. 5 % by pressure transducers yielding an electrical signal. Special protective devices guarded against damage caused by catastrophic specimen failure.

The new universal tester found extensive use not only for calibrating NASA's rocket engines and other aerospace components but also for calibrating commercial and manufacturing weighing equipment.

Pieces of the Moon

Three Apollo missions brought back to earth samples taken from the moon. The samples were obtained by astronauts Neil A. Armstrong and Edwin W. Aldrin, Jr. (Apollo 11); Charles Conrad, Jr. and Alan L. Bean (Apollo 12); and Alan B. Shepard, Jr. and Edgar D. Mitchell (Apollo 14). Portions of the "moon rocks" were brought to NBS for examination. At the Bureau, the samples were analyzed and compared with terrestrial materials of similar composition. Materials from a meteorite crater in Arizona were included in the comparisons as well, yielding interesting and useful information on the age and sources of materials on the lunar surface.

Several groups of scientists, both from NBS and collaborating laboratories, participated in the studies. Kurt F. J. Heinrich and his colleagues used an electron microprobe in their work. They found and analyzed minerals in the lunar samples that were common on the earth's surface. The form of some of the Apollo 11 samples indicated the occurrence of meteorite impacts on the moon.[163]

Harvey Yakowitz and his collaborators found a great variety of minerals in an Apollo 11 sample, using three types of microanalysis. They concentrated their efforts on metallic particles that contained iron and nickel. Like Heinrich's group, they found evidence of meteor impact on the moon—certain of the samples resembled minerals found in meteor craters in the American west. [164] Similar results were obtained by David B. Ballard, Yakowitz and J. I. Goldstein in a study of Apollo 11 and 12 soils.[165]

Apollo 12 soil samples were examined by Yakowitz and Goldstein, who found nickel and cobalt in igneous rock. Some 80 % of the metallic regions studied showed compositions different from those expected even for meteorites; they appeared to have undergone "cooking" for a year or more at temperatures in the range 500 °C to 600 °C.[166]

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[163] I. Adler, L. S. Walter, P. D. Lowman, B. P. Glass, B. M. French, J. A. Philpotts, K. F. J. Heinrich, and J. I. Goldstein, "Electron microprobe analysis of Apollo 11 lunar samples," *Geochim. Cosmochim.* **34**, Suppl. 1, pp. 87-92, January 30, 1970.

[164] J. I. Goldstein, E. P. Henderson, and H. Yakowitz, "Investigation of lunar metal particles," *Geochim. Cosmochim. Acta* **1**, pp. 499-512 (1970).

[165] D. B. Ballard, H. Yakowitz and J. I. Goldstein, "Study of metals in the lunar soil," *Proc. 4th Annual Scanning Electron Microscope Symposium, ITT Research Institute, Chicago, April 29, 1971,* Part 1, pp. 169-176 (1971).

[166] J. I. Goldstein and H. Yakowitz, "Metallic inclusions and metal particles in the Apollo 12 lunar soil," Chapter in *Proc. 2nd Lunar Science Conf., Houston, January, 1971,* **1**, pp. 177-191 (1971).

Heinrich also collaborated in a study of five Apollo 12 rocks. Again, the investigators found ready comparisons with earthly minerals.[167]

Isotopic abundance ratios on Apollo 14 samples were obtained by a group that included I. Lynus Barnes, B. Stephen Carpenter, Ernest L. Garner, John W. Gramlich, Edwin C. Kuehner, Lawrence A. Machlan, E. June Maienthal, John R. Moody, Larry J. Moore, Thomas J. Murphy, Paul J. Paulsen, Keith M. Sappenfield, and William R. Shields. Probing for the elements U, Pb, Rb, Sr, Ca, and Cu, they found little variation from terrestrial minerals. Dating by isotopic lead ratios indicated ages for the samples of more than 4×10^9 years.[168]

Other Bureau activities impinging on space and astronomy during this time period are mentioned under different headings.

Precision Measurement Grants

During August 3-7, 1970, the International Conference On Precision Measurements and Fundamental Constants was held at NBS.[169] The General Chairman of the conference was Bureau Director Lewis Branscomb. In his remarks, he announced the establishment of a new program to encourage work in all specialties of precision measurement. The new program would be known as Precision Measurement Grants (PMG), said Branscomb. Each grantee would receive from NBS the sum of $15,000.

Recipients of the first three grants were Prof. James E. Faller of Wesleyan University, Prof. Daniel A. Kleppner of MIT, and Prof. Hugh G. Robinson of Duke University. Initial grant applications were judged by a committee composed of members of the Joint Institute for Laboratory Astrophysics with the assistance of an advisory board of distinguished metrologists.

This program of grants to facilitate and encourage work at U.S. colleges and universities in precision measurement—though not a large enterprise—led to significant advances over the years in many different areas of physics and metrology. In some cases—such as that of James Faller, whose work we saw in the section on lunar ranging—the grants helped bring to NBS scientists already familiar with the nature of research in precise measurement.

By the summer of the year 2000, the program was in its 30th year. Awards had been made to 66 scientists, two of whom—Steven Chu of Stanford University and Daniel C. Tsui of Princeton University—had won Nobel prizes in physics for work

[167] B. M. French, L. S. Walter, K. F. J. Heinrich, P. D. Loman, Jr. , A. S. Doan, Jr. , and I. Adler, "Compositions of major and minor minerals in five Apollo 12 crystalline rocks," *NASA Special Publication 306,* 142 pp., 1972.

[168] I. L. Barnes, B. S. Carpenter, E. L. Garner, J. W. Gramlich, E. C. Kuehner, L. A. Machlan, E. J. Maienthal, J. R. Moody, L. J. Moore, T. J. Murphy, P. J. Paulsen, K. M. Sappenfield, and W. R. Shields, "Isotopic abundance ratios and concentrations of selected elements in Apollo 14 samples," *Geochim. Cosmochim. Acta* **2**, pp. 1465-1472 (1972).

[169] *NBS Technical News Bulletin* **54**, pp. 268-270, November 1970.

accomplished subsequent to their participation in the PMG program. The amounts of the grants had increased by then to $50,000 annually, and they were renewable for two additional years.

From 1975 to the present year, the PMG program was administered by Barry N. Taylor of NBS.

NBS Nuclear Reactor Completes Its First Year At Full Power

The Bureau's nuclear reactor, which first "went critical" in December of 1967, completed its first year at full power during October 1970. Taking stock of the year's progress, Reactor Radiation Division Chief Robert S. Carter expressed satisfaction both with the flawless operation of the reactor and with the quality and number of the technical projects accomplished there.[170]

The reactor was first licensed to operate at 10 MW. Its nuclear fuel, uranium enriched in the isotope ^{235}U, was contained in a set of 30 cylindrical rods arranged in three hexagonal rings. During reactor operation, the ^{235}U content in replacement fuel elements was gradually increased, allowing longer operation between refueling events. As operating experience grew, an ever larger ^{235}U content—as much as 250 g—was incorporated into replacement fuel elements, in the hope of achieving 9-10 days of operating life.

NBS scientists and administrators clasped hands in anticipation of the moment when its new nuclear reactor would go critical. Standing from left to right were Allen Astin, Harry H. Landon, Carl Muehlhause, Robert S. Carter, and Irl C. Schoonover. Seated behind them on the right was Ivy M. Collier.

[170] Robert S. Carter, "Reactor Radiation Division: Annual Progress Report for the Period Ending October 31, 1970," *NBS Technical Note 567*, March 1971, 58 pp.

An optimal fuel-rotation scheme was studied, along with careful monitoring of the shape of the nuclear flux pattern within the reactor. Generally speaking, best results seemed to involve removal of elements from the inner ring and the moving of partially consumed elements from the outer rings toward the center. Efficient replacement was important from a cost point of view; the percentage burnup of the ^{235}U fuel increased from 19 % at startup to nearly 40 % with the use of higher-density fuel elements and improved replacement pattern.

The reactor was built to serve a large variety of users from within NBS and from other government agencies, universities and industry. This pattern of use was followed from the start.

The Reactor Radiation Division consisted of three sections—Reactor Operations, Engineering Services, and Neutron Physics. Knowledgeable reactor physicists from outside the division planned and conducted their own irradiation sequences. The division staff assisted other scientists and technical workers in planning and carrying out irradiations so as to provide needed information or samples.

Four neutron diffractometers were available for crystal-structure analysis. A time-of-flight instrument permitted the study of inelastic neutron scattering. Thermalized neutrons were available for experiments in yet another facility. Further facilities were still in the developmental stage in 1970.

During the fueling process prior to criticality tests, Harry H. Landon, Chief of the NBS Neutron Nuclear Physics Section, checked the nuclear reactor core configuration through a periscope while Robert S. Carter, Chief of the Neutron Solid State Physics Section, observed.

Change in the neutron flux in the NBS Reactor was monitored in the control room by (from left to right) Larry Smith, Arthur Chapman, and Albert W. Crebs as control rods were withdrawn to achieve criticality.

A time-shared computer was used to control all the experimental devices, with stations available for all users. Use of the time-shared computer permitted coordination of the various irradiation experiments and quick evaluation of results.[171]

During the first full year of operation, more than 1,500 in-core irradiations were undertaken on a total of nearly 10,000 samples for purposes as diverse as biology, medicine, activation analysis, isotope production, and study of radiation effects. Some of the agencies involved in these irradiations included the U.S. Geological Survey (identification of trace constituents in geological materials); Food and Drug Administration (halogen and mercury concentrations in various commercial products, including foods); U.S. Post Office, Internal Revenue Service, and Federal Bureau of Investigation (activation analysis in crime-detection studies); Army Institute of Dental Research (role of trace metals—for example, zinc—in bone healing); Teledyne Isotopes, Inc. (study of fission products from transuranium isotopes); and the University of Maryland (mercury levels in oysters from the Chesapeake Bay).

[171] H. A. Alperin and E. Prince, "A time-shared computer system for diffractometer control," *J. Res. NBS* **74C**, pp. 89-95 (1970).

Among other technical projects performed at the reactor, many involved NBS scientists both within the Reactor Radiation Division and from other divisions. Although it is not possible to mention all of these first-year projects, their variety gave a strong indication of the enormous power of the nuclear reactor as a research tool.

Antonio Santoro joined NBS as a member of the Reactor Radiation Division in November of 1964, while the reactor was still under construction. He and his Bureau colleagues Marcello Ziocchi, Curt W. Reimann and Alan D. Mighell utilized single-crystal x-ray diffraction techniques elsewhere to analyze the crystal structures of several transition-metal complexes with particular emphasis on understanding the interactions between metal ions and ligand molecules.[172] However, once the neutron-diffraction facilities at the reactor became available, the team could utilize that capability to obtain unambiguous assignment of atoms such as the carbon and nitrogen in the pyrazole group and to obtain more reliable information regarding the presence or absence of hydrogen-bonding in these molecules.[173]

Other crystal-structure analysis work done using the reactor's neutron-diffractometer facilities included the following:

- Observations on potassium silicotungstate, undertaken by Edward Prince and his colleagues from Georgetown University, P. M. Smith and J. V. Silverton, to determine the configuration of the silicotungstate ion and to elucidate the role of water of hydration in the crystal.

- Dimethyl sulfone diimine, a relative of synthetic detergents, studied by Prince and J. Bevan of the Proctor & Gamble Co. to ascertain the positions of the hydrogen bonds.

- Apophyllite, examined by Prince, A. A. Colville of California State College, and G. Donnay of the Carnegie Institution of Washington in order to work out the unusual sheet structure of this crystal.

- Durene, a tetramethylbenzene, studied by Prince, John J. Rush and Leroy W. Schroeder, a Postdoctoral Research Associate, to obtain insight into the conformation of the methyl groups in this crystal as well as the origin of their hindered rotation.[174]

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[172] A. Santoro, A. D. Mighell, M. Ziocchi and C. W. Reimann, "The crystal and molecular structure of hexakis (imidazole) nickel(II) nitrate, $(C_3H_4N_2)_6Ni(NO_3)_2$," *Acta Cryst.* **B25**, pp. 842-847 (1969). See also A. D. Mighell, C. W. Reimann and A. Santoro, "The crystal structure of dibromotetrapyrazolenickel(II), $Ni(C_3H_4N_2)_4Br_2$," *Acta Cryst.* **B25**, pp. 595-599 (1969).

[173] A. Mighell, A. Santoro, E. Prince and C. Reimann, "Neutron diffraction structure determination of dichlorotetrapyrazolecopper(II), $Cu(C_3H_4N_2)_4Cl_2$," *Acta Cryst.* **B31**, pp. 2479-2482 (1975).

[174] E. Prince, L. W. Schroeder and J. J. Rush, "A constrained refinement of the structure of durene," *Acta Cryst.* **B29**, pp. 184-191 (1973).

- Potassium cyanide and sodium cyanide, examined by John J. Rush and his colleagues from Argonne National Laboratory, J. Michael Rowe, D. G. Hinks, D. L. Price, and S. Susman, in order to understand how the linear cyanide groups were able to display cubic symmetry at temperatures near the melting point of the crystal.[175] Soon after this work was accomplished, Rowe joined the NBS staff.

Rush, Schroeder, and their colleague A. J. Melveger of the Allied Chemical Corp. performed a detailed study of the crystal and molecular dynamics of sodium bifluoride, using the techniques of infrared and Raman spectroscopy as well as inelastic neutron scattering. In this way they were able to gain information on the acoustic and optical translational lattice modes of vibration and to assign approximate values to the vibrational frequency distribution.

Bert Mozer and his collaborator L. A. de Graaf of Argonne National Laboratory utilized the neutron diffraction method to measure the structure factors of liquid neon at 35 K as functions of liquid density. Radial distribution functions, direct correlation functions, and effective interatomic potentials were calculated from the data.[176] Mozer also participated in preparing for use a two-axis spectrometer with a neutron-energy analyzer facility. The equipment could be used as a time-of-flight spectrometer or for three-axis crystal spectrometry. In the time-of-flight mode, the system utilized a 4 m evacuated flight tube with a group of eight detectors, producing an energy resolution as fine as 2 %.

In its schedule of projects focusing on collaboration with other government agencies, the division staff worked with members of the Naval Ordnance Laboratory on crystal structures, magnetic structures, the time-shared computer system, and a superconducting magnet for high-magnetic-field studies. With members of the Naval Research Laboratory (including Jerome Karle, awarded the Nobel Prize for chemistry in 1985 for his work with Herbert A. Hauptmann on the development of direct methods for the determination of crystal structures), they studied the properties of amorphous solids. With C. S. Schneider of the U.S. Naval Academy, they performed precise measurements of thermal-neutron scattering amplitudes. And with the staff of the Picatinny Arsenal, they characterized metastable materials; the Picatinny Arsenal group was pleased to find a replacement for the experimental facilities denied them when the Army nuclear reactor at Watertown, Massachusetts was decommissioned.

Beginning in its first year, the nuclear reactor also provided experimental facilities for Bureau employees from other divisions, often in collaboration with colleagues from other organizations. Philip D. LaFleur of the Analytical Chemistry Division, for example, collaborated with W. F. Marlow and Donald A. Becker of the Reactor Research

[175] D. L. Price, J. M. Rowe, J. J. Rush, E. Prince, D. G. Hinks and S. Susman, "Single crystal neutron diffraction study of potassium cyanide," *J. Chem. Phys.* **56**, pp. 3697-3702 (1972). See also J. M. Rowe, D. G. Hinks, D. L. Price, S. Susman and J. J. Rush, "Single crystal neutron diffraction study of sodium cyanide," *J. Chem. Phys.* **58**, pp. 2039-2042 (1973).

[176] L. A. de Graaf and B. Mozer, "Structure study of liquid neon by neutron diffraction," *J. Chem. Phys.* **55**, pp. 4967-4973 (1971).

Division in a long-term program of neutron-activation analysis.[177] Another group, from the Optical Physics Division—Richard D. Deslattes, William C. Sauder, James A. Hammond and Albert Henins—initiated a program of measurement of atomic constants.

Several groups from the Nuclear Radiation Division commenced experimental programs:

- James A. Grundl, in collaboration with colleagues at the Los Alamos Scientific Laboratory, began preparing an intense ^{235}U fast neutron source, using the thermal neutron column.
- Ivan G. Schroder and his colleagues from Harvard University (J. L. Alberi and R. Wilson) and from Brookhaven National Laboratory (G. Scharff Goldhaber) set up a Cd target for the study of parity-conservation in strong interactions.[178]
- Frank J. Schima began a study of the decay characteristics of krypton isotopes.
- Alan T. Hirshfeld, Dale D. Hoppes, Wilfrid B. Mann and Frank Schima prepared samples of the isotope ^{82}Br for use in nuclear orientation studies.[179]

Water and Polywater

Water is thought by the layman to be the most ordinary of substances. "H-2-O," he will say if asked, proud that he knows a chemical formula, "two protons stuck to an oxygen atom. So what?" But water is so common and its properties so well-known that one often forgets that its properties are not what one would expect from its atomic makeup. Its unusual properties include the following:[180]

- A surprisingly high boiling point (100 °C or 212 °F) considering its small molecular size.
- A peculiar density-*vs*-temperature pattern. Most—though not all—substances become progressively denser as their temperature is reduced, with the frozen solid more dense than the liquid. It is very important to life on earth that ice is *less* dense than water. Ice forms on the surface of lakes and rivers, insulating

[177] W. F. Marlow and P. D. LaFleur, "Standard reference materials for the analysis of environmental samples," in *Proc. Symp. Nuclear Techniques in Measurement and Control of Environmental Pollution, Salzburg, Austria, Oct 26-30, 1970,* International Atomic Energy Agency, Vienna Austria, March 1971, pp. 91-94.

[178] J. L. Alberi, R. Wilson and I. G. Schroder, "Parity violation in neutron-capture gamma rays," *Phys. Rev. Lett.* **29**, No. 8, 518-521 (1972).

[179] A. T. Hirshfeld, D. D. Hoppes, W. B. Mann and F. J. Schima, "Nuclear orientation of ^{82}Br in iron," *Proc. Intl. Conf. on Hyperfine Interactions in Excited Nuclei, Rehovot, Israel, Sept 6-11, 1970*, Chapter in *Hyperfine Interactions in Excited Nuclei* **1**, 335-338 (Gordon & Breach Sci. Publ., New York, NY, 1971).

[180] Felix Franks, "Polywater," (Cambridge, MA: The MIT Press, 1981) 208 pp.

living plants and animals in those waters from freezing weather above and—in temperate climates—melting completely during the summer season. The mechanism by which water at 0 °C becomes more dense as it is heated is not entirely clear, but it is a fortunate fact that water reaches a maximum density above 0 °C (actually at 4 °C).

- An unusually large heat capacity. For a small molecule, water exhibits an anomalously large heat capacity, allowing it to serve nature as an enormous energy-storage reservoir.
- An increase in the vapor pressure when dispersed in small droplets. Lord Kelvin noticed nearly a century ago that the vapor pressure of water is unusually large in micrometer-sized droplets. He composed an equation to relate the vapor pressure to the droplet curvature. Is it unusual to find water in such small spaces in nature? Not at all, it turns out: many minerals and many biological materials contain confined spaces of magnitudes that are small enough to warrant use of the Kelvin relations. Among these substances are the human blood system, water droplets in clouds, and interstices in certain rocks.

It is such unusual properties of water as these, as well as the absolute importance of water to biological life, that has always impelled scientists to experiment with water. Any new understanding of the humble liquid that they could achieve would potentially affect all humanity.

In the case that follows, hard-working scientists thought they had found an unusual new property of water—until the use of newly developed, sharper tools showed them otherwise.

"Anomalous Water"

Given the importance of water to mankind, it was not surprising that a Russian scientist—one Nikolai N. Fedyakin, working in relative obscurity in the Technological Institute in Kostroma a few hundred kilometers northeast of Moscow—devoted himself to a study of water sealed in fine capillaries of diameter 2-4 μm. Careful and methodical, Fedyakin purified his water samples, encapsulated them and watched them. When he found in 1962 that certain of the samples seemed very slowly (over periods of many days) to separate into two fractions, one above the other in the capillary, his interest picked up considerably. Why should the water separate? Were there two components in his purified water samples? What properties would the new fraction exhibit?

Although further experiments were difficult—only a few micrograms of material was available for test—he nevertheless found that the new fraction showed a density that was clearly larger than that of ordinary water. When he was confident of his results, he published a paper describing them. In this first paper, Fedyakin expressed no knowledge of the composition of the separated fraction in his capillaries; he only noted that he had seen "anomalous water."[181]

[181] N. N. Fedyakin, "Change in the structure of water during condensation in capillaries," *Kolloid Zhurnal* **24**, 497 (1962); (translation: *Colloid Journal USSR* **24**, 425 (1962).

Fedyakin's report—available for some time only in Russian—attracted no immediate attention outside Russia. It was considered very interesting, however, by the group headed by Boris V. Deryagin at the Institute of Physical Chemistry in Moscow. Recognizing potential importance in Fedyakin's work, they immediately formed a collaborative project with him. Subsequent publication and discussion of new separation experiments with "anomalous water" came from Deryagin's laboratory. The first such paper, containing startling information on the properties of the condensed fraction, was published (again in Russian) in 1967.[182]

Gradually the news reached Western scientists that ordinary water, when allowed to re-condense in fine capillaries, might be exhibiting strange long-range-order properties. The new fraction showed anomalously high viscosity, large thermal expansion, increased boiling-point temperature and reduced freezing-point temperature, as well as the higher density found by Fedyakin. In talks at scientific meetings, Deryagin began to speculate that ordinary tap water might really be a metastable state, changing to a stabler form in contact with certain solid surfaces. Heady stuff for such a prosaic liquid!

The Russian results were corroborated by a group from the Unilever Research Laboratories in Cheshire, England.[183] They mentioned Deryagin's interesting speculation as their primary motivation. Placing numerous Pyrex capillaries of 10-100 μm diameter in a desiccator at room temperature and reduced pressure, they found condensed columns in "about 5 %" of the capillaries after a few days. They sealed the capillaries containing the condensate and found some of them to contain a gel-like residue. Mass-spectrometric analysis showed only mass 17 and 18, typical of water.

NBS Experiments On "Polywater"

One of the first American groups to follow up on the Russian "anomalous water" results was formed by Robert Stromberg, Deputy Chief of the NBS Polymers Division, and Ellis Lippincott, professor of chemistry at the University of Maryland and Director of the Center for Materials Research there. Together with Warren H. Grant of the Polymers Division and Gerald L. Cessac, a predoctoral student at Maryland, they prepared many samples of "anomalous water" by condensing purified water in Pyrex and quartz capillaries of 5-20 μm interior diameter, either at reduced pressure or full saturation pressure. They noted that the sample yield was very small, causing severe problems in analysis of the material. Nevertheless, they analyzed their "anomalous water" using laser-probe excitation, finding only "small" quantities of sodium and silicate impurities. Their analytical method was only slightly sensitive to the light hydrogen and oxygen atoms that make up the water molecule.

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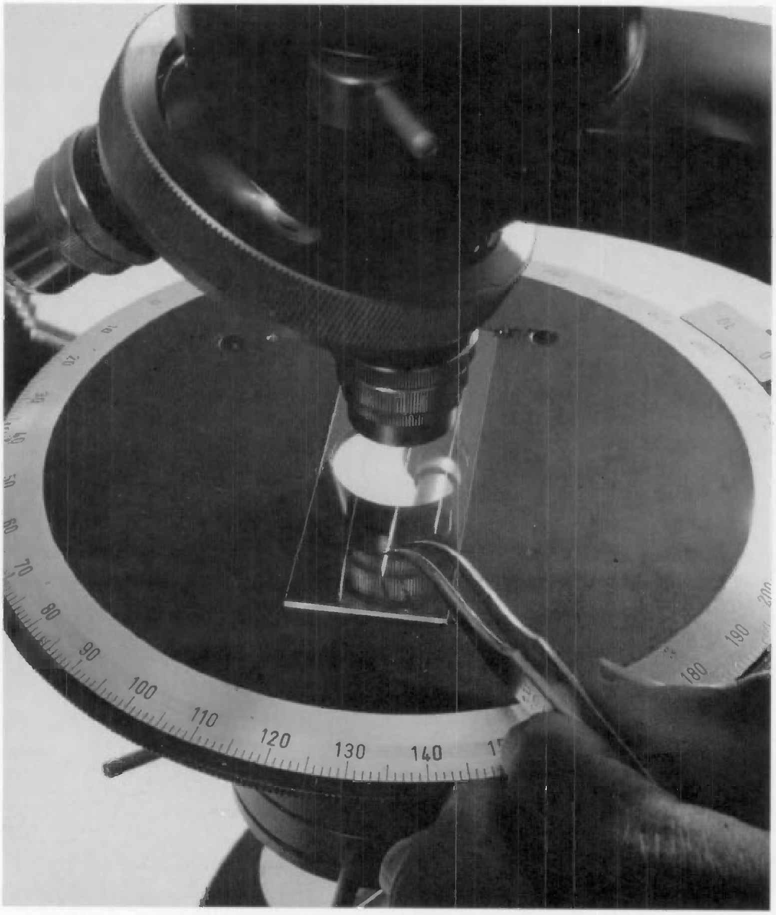
[182] B. V. Deryagin, N. V. Churaev, N. N. Fedyakin, M. V. Talayev, and I. G. Yershova, "The modified state of water and other liquids," *Bulletin of the Academy of Sciences of the USSR (Izv. Akad. Nauk SSSR, Ser. Khim.)*, No. 10, pp. 2178-2187, 1967.

[183] E. Willis, G. K. Rennie, C. Smart, and B. A. Pethica, "'Anomalous Water,'" Letter to the Editor, *Nature* **222**, 159, April 12, 1969.



Quartz capillaries containing anomalous water samples were studied by microscopy as well as by spectroscopic techniques.

An exciting find by the NBS-Maryland group came when they analyzed infrared spectra of the samples. The spectra looked nothing like those of ordinary water! Instead, the results indicated the presence of a polymer. In publishing their results, they portrayed two polymeric forms of water that appeared possible, and they coined the term "polywater" to describe the sample material.[184]

Stromberg and Lippincott were not in a position to know that they had fallen into a trap. The analytical methods they used were not sensitive enough to give them a full picture of the microgram-sized contents of their capillaries. Hints there were in the identification of sodium ions and silicates in the condensate, but they had no way of knowing that such impurities in reality dominated the spectra given by their samples.

[184] E. R. Lippincott, R. R. Stromberg, W. H. Grant, and G. L. Cessac, "Polywater," *Science* **164,** 1482-1487, June 1969.

Polymers Division scientists Robert R. Stromberg and Warren H. Grant discussed possible polymeric structures of water.

The name "polywater" captivated both the group's scientific colleagues and the public at large. Considerable experimentation and more speculation emerged from many sources over the following three-year period. All together, about 450 references to "anomalous water" or "polywater" appeared over the next forty-odd months[185] despite unsettling results that began to appear early in 1970.

[185] Bruce C. Bennion and Laurence A. Neuton, "The epidemiology of research on 'Anomalous Water.'" *J. Amer. Soc. for Information Science* **27**, No. 1, pp. 53-56 (1976).

Questions About Impurities

In March 1970, the journal Science carried back-to-back articles that raised the question of impurities as the source of the unusual properties of the "anomalous water." The first, written by D.L. Rousseau of the Bell Telephone Laboratories at Murray Hill, NJ and S.P.S. Porto of the University of Southern California, discussed a special effort to prepare "pure polywater" and then to analyze it.[186] The two scientists boiled ordinary quartz tubing in aqua regia, a powerful cleaner composed of nitric and hydrochloric acids, and rinsed the tubing in distilled water prior to drawing the tubing into hundreds of capillaries. They washed all glassware sequentially in acetone, in water distilled several times, in chromic acid, and again in distilled water. They mounted the capillaries in two different ways in their desiccator—by leaving them in contact with the desiccator walls, and by suspending them from fine wires above a pool of distilled water. The suspended group of capillaries was included in order to minimize "creep" of stopcock grease or other impurities contained within the assembly.

"Anomalous water" condensed in 1 % to 5 % (more with higher chamber pressure) of the capillaries that Rousseau and Porto placed on the bottom of the desiccator, but no condensate formed in any of the suspended capillaries (an obvious clue to the possible role of impurities). The authors allowed the condensate to dry for about a week to evaporate all normal water prior to analyzing the residue.

Infrared and Raman spectroscopic analysis of the residue in the capillaries containing the dried condensate showed a substantial amount of sodium impurity—20 % to 60 % by weight. Also appearing were chloride and sulfate ions (each about 15 %) and smaller amounts of potassium and calcium.

The other March 1970 *Science* article was written by S. L. Kurtin and C. A. Mead of the California Institute of Technology in collaboration with W. A. Mueller and B. C. Kurtin of the Stanford Research Institute in South Pasadena, California and with E. D. Wolf of the Hughes Research Laboratories in Malibu, California.[187] This group prepared anomalous water samples in the "standard" manner, then centrifuged the condensate to obtain about 2 μg of material for examination. Mechanical and infrared studies showed the expected results, but further testing by dielectric methods indicated the presence of sols of particulates in ordinary water. Examining the samples with a scanning electron microscope showed "fluffy" particles, unlike control samples of ordinary distilled water.

Sharper Tools and a Discarded Idea

A January 1971 number of Science contained an extensive report discouraging the notion that there existed a high-polymer form of water. Written by collaborators R. E. Davis from Purdue University, D. L. Rousseau from the Bell Telephone

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[186] D. L. Rousseau and S. P. S. Porto, "Polywater: polymer or artifact?" *Science* **167**, March 27, 1970, p. 1715.

[187] S. L. Kurtin, C. A. Mead, W. A. Mueller, B. C. Kurtin, and E. D. Wolf, "Polywater: a hydrosol?" *Science* **167**, March 27, 1970, p. 1720.

Laboratories, and R. D. Board from the Hewlett-Packard Corporation laboratory, the report offered spectroscopic results on samples prepared at the Bell Laboratories and at Purdue.[188] The ESCA (electron spectroscopy for chemical analysis) technique turned up a veritable soup of impurities; sodium and potassium salts of the sulfate, chloride, nitrate, borate and silicate ions, as well as compounds containing the C-O bond.

Davis and his group had used the usual techniques to prepare their samples, drying or sealing them before analysis. They emphasized that all their samples showed impurities and that all ESCA and infrared spectral lines were accounted for without need to invoke polymerization of water.

By the end of 1970, the NBS/University of Maryland group had come to question their own earlier speculations regarding anomalous water. Further experimentation had turned up evidence indicating the presence of impurities in their preparation techniques. They described this work in the *Journal of Colloid and Interface Science.*[189]

The debate over anomalous water and polywater continued for some time, but evidence that water vapor developed a remarkable reactivity with glass or quartz—especially when the silicate was subjected to the type of strain induced by drawing, as it was in the process of forming capillaries—continued to mount. Water, it seemed, was indeed an unusual substance—but it did not polymerize.

An epitaph of sorts for the polywater episode was written by Theodor Benfey of Guilford College, who wrote an editorial for the journal *Chemistry.*[190] He noted that remarks made during a 1971 symposium by the Russian scientist Deryagin had been revised by him prior to later publication of the symposium proceedings. The revised comments included the statement that "anomalous water" contained significant amounts of silicon, probably in the form of silicic acid gel or silica gel, and that quartz definitely dissolved more readily on exposure to water vapor than it did in liquid water. Even in Russia, water continued to be an unusual substance, but not a polymeric one.

The case of "polywater" served to remind scientists in the Soviet Union, at NBS, and elsewhere to move with caution into unknown areas. Unexpected results of experiments on the humblest of earthly substances—water—had been interpreted too quickly as indicators of an exciting possibility. Such things happen in science.

Advances in Microscopy

The Electron Microprobe in Color

The scanning electron microprobe was developed as an analytical tool during the 1950s. It was added to the NBS chemical-analysis arsenal chiefly by Kurt F. J. Heinrich when he joined the Bureau in 1964 as chief of the Microanalysis Section of

[188] R. E. Davis, D. L. Rousseau, and R. D. Board, "Polywater: Evidence from electron spectroscopy for chemical analysis (ESCA) of a complex salt mixture," *Science* **171**, 167 (1971).

[189] Ellis R. Lippincott, Gerald L. Cessac, Robert R. Stromberg, and Warren H. Grant, "Polywater—a search for alternative explanations," *J. Colloid and Interface Sci.* **36**, No. 4, 443-460 (1971).

[190] T. Benfey, "Last word on polywater?" *Chemistry* **46**, No. 8, p. 4 (Editorial), September 1973.

the Analytical Chemistry Division.[191] Some of the capabilities of the device were evident in the note on "moon rock" analysis (in a previous section).

In principle, the technique was simple enough; a beam of energetic electrons was directed at a target, generating x rays whose energy depended upon the atomic number of the target constituents. By analyzing the energy and intensity of the x-ray spectrum as functions of the electron-beam location on the target, the operator could construct a map of the target that showed the identity and concentration of its constituent elements at each position. The map usually was rendered as one or more black-and-white microphotographs of the target area, with one picture for each impurity scan.

There were plenty of complications to the technique. The analytical methods were not especially simple and, typically, specimens were necessarily prepared with microscopically smooth surfaces to avoid distortion of the x-ray spectrum. Nevertheless, the electron microprobe developed into a powerful tool for chemical analysis.

The principal applications of electron microprobe analysis included metallurgy, mineralogy, ceramics, polymers and biology, with the last generally limited by the unresponsiveness of biological constituents (hydrogen, carbon, and oxygen), owing to their low atomic numbers.

Early in 1969, Heinrich and his colleague Harvey Yakowitz of the Metallurgy Division published a treatise on the conversion of the multiple black-and-white microprobe scans to single photographs in color, greatly simplifying the interpretation of the electron microprobe data.[192] Their technique, one of three methods initially proposed to introduce color into the analytic process, was to use the black-and-white scanning images as color-separation positives with different color filters for each scanned element.

In their paper, Yakowitz and Heinrich discussed the procedures required to prepare the composite color prints, including the use of fast color film, such as Polaroid, to quickly and inexpensively produce color images. By careful choice of the color filters, the operator could identify regions containing single elements as well as multiple-element areas of a particular sample.

New Scanning Electron Microscope Facility

During 1969 a new scanning electron microscope was installed in the laboratories of the Lattice Defects and Microstructures Section of the Metallurgy Division. A complement to the electron microprobe, it quickly became a favorite tool for an

[191] For an introduction to this topic, see, for example, S. J. B. Reed, "Electron microprobe analysis," Second edition, Cambridge University Press, 1993, 326 pp. See also "The Electron Microprobe: Proceedings of the Symposium Sponsored by the Electrochemical Society, Washington, DC, October, 1964," T. D. McKinley, K. F. J. Heinrich, and D. B. Wittry, Editors, John Wiley & Sons, Inc., New York, 1966. The latter includes an extensive, indexed bibliography through 1964.

Use of the electron microprobe for quantitative analysis was the topic of "Quantitative electron probe microanalysis, Proceedings of a seminar held at NBS, Gaithersburg, MD, June 12-13, 1967," K. F. J. Heinrich, editor, *NBS Special Publication 298,* October 1968, 305 pp.

[192] Harvey Yakowitz and Kurt F. J. Heinrich, "Color Representation of Electron Microprobe Area-Scan Images by a Color Separation Process," *J. Res. NBS* **73A**, No. 2, 113-124, 1969.

interesting variety of studies, including lunar-rock samples, strained and fractured metals, dental surfaces, and tiny electronic devices. Its electron-beam probe produced images of 25 nm resolution that exhibited substantial depth of field. Unlike the earlier transmission electron microscope, thick samples with irregular surfaces could be observed with the SEM.

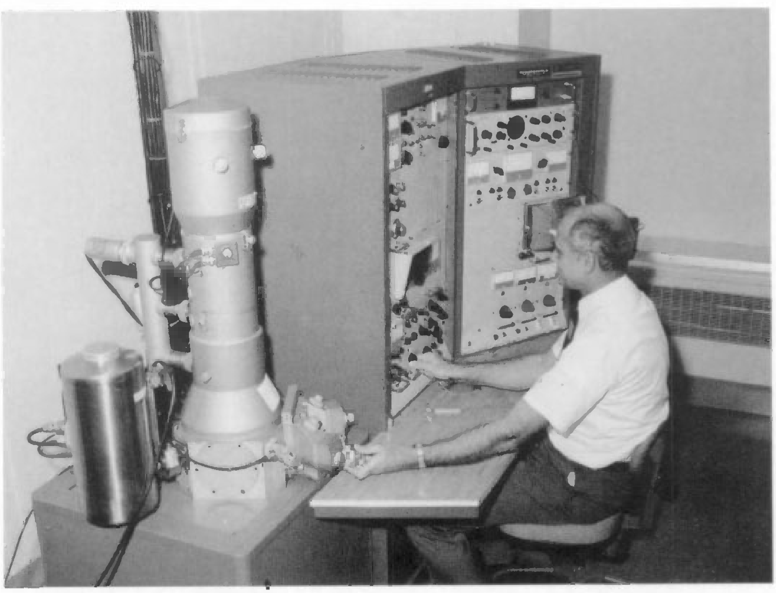
The first principal operator of the new device was David B. Ballard, an Indiana-bred metallurgist trained at the Virginia Polytechnic Institute. He found the microscope useful for his own work on the study of metallic fracture, and he also assisted colleagues in its use. Some thirty NBS scientists employed the new instrument within the first two years of its installation.

Chemistry Research

This section conveys some of the broad range of NBS studies during the early 1970s in the field of chemistry.

Chemical Impurities at Parts Per Billion

Combining the techniques of isotope dilution and spark-source mass spectrometry, an Analytical Chemistry Division group including Paul J. Paulsen, Robert Alvarez, and Daniel E. Kelleher found that they could detect impurity elements at concentrations as



David B. Ballard readied for operation the NBS scanning electron microscope and its associated electronics.

low as about 10^{-9}. In certain applications, for example in nuclear physics and electronics, the presence of impurities at that level could render a material useless for its intended purpose.

The method used by the group relied upon the use of enriched isotopes provided by external producers such as the Oak Ridge National Laboratory. Adding isotopes of a suspected impurity to a sample of the test material, then performing spark-source mass spectrometry, the group could evaluate the original concentration of the impurity at the extremely low levels desired. Initial tests of the method were successful in both platinum and zinc samples.[193]

Chemical Analysis With Flame Spectroscopy

The limit of detection for trace impurities receded noticeably as a result of a new method introduced by Analytical Chemistry Division researchers Oscar Menis, Theodore C. Rains, Kenneth W. Yee, and Herbert D. Cook, and W. Snelleman, their colleague from the Rijksuniversiteit in Utrecht, Netherlands. The group developed a flame-emission spectrometer which performed a rapid repetitive scan of a narrow wavelength region, minimizing spectral interference from the matrix in which the trace elements were held.

Key to the small, new device was a quartz plate vibrating at 145 Hz, and an amplifier tuned to twice that frequency. By providing a second-derivative signal, the new instrument gained substantially in sensitivity, eliminating the need for a monochromator of high resolving power. A second benefit was the ability of the device to identify trace elements in only 50 microliters (roughly a cube 3.6 mm on each side) of solution, extending the method to biochemical studies and monitoring of air pollution where sample sizes were necessarily tiny.[194]

Using Liquid Sodium Safely

During the late 1960s and early 1970s, liquid sodium was used as a heat-exchange fluid in certain nuclear power reactors. The application took advantage of the favorable thermodynamic and nuclear properties possessed by the liquid metal. However, sodium was inherently dangerous because of its extreme chemical reactivity. Some thought that the most corrosive properties of sodium arose from the presence of trace quantities of carbon or oxygen.

Detecting carbon and oxygen impurities in sodium and quantifying their amounts was not an easy problem, but it was one that George J. Lutz and Larry W. Masters could do. They used a combination of photon-activation analysis and rapid chemistry

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[193] R. Alvarez, P. J. Paulsen, and D. E. Kelleher, "Simultaneous determination of trace elements in platinum by isotope dilution and spark source mass spectrometry," *Anal. Chem.* **41**, No. 7, 955-958 (1969). See also P. J. Paulsen, R. Alvarez, and D. E. Kelleher, "Determination of trace elements in zinc by isotope dilution spark source mass spectrometry," *Spectrochim. Acta* **24B**, 535-544 (1969).

[194] W. Snelleman, O. Menis, T. C. Rains, K. W. Yee, and H. D. Cook, "Flame emission spectroscopy with repetitive optical scanning in the derivative mode," *Anal. Chem.* **42**, No. 3, 394-398 (1970).

to accomplish the job. They irradiated sodium samples with bremsstrahlung from the NBS electron linear accelerator, converting ^{16}O, the common isotope of oxygen, to ^{15}O; similarly, ^{12}C, the common isotope of carbon, was converted to ^{11}C. Rapid chemical separations were needed because the two light isotopes had half-lives of 2 min and 20 min, respectively.

For oxygen, Lutz found yields of about 50 % and a detection limit of about 2 ppm.[195] Lutz and Masters, using similar methods, could detect carbon as an impurity at levels below 1 ppm.[196]

Research on Reactive Molecules

In all probability, the parent of excitation chemistry at the Bureau was a 1954 discovery by Herbert P. Broida and John R. Pellam of strange glows and bright flashes from a dewar wall held at 4.2 K. Curious about the possibility of creating energetic new fuels for rocketry, they had diverted gases such as nitrogen, hydrogen, and oxygen through an electrical discharge, thus creating molecular fragments with unpaired electrons—free radicals.[197] It seemed possible that the highly energetic fragments could be stored at low temperatures for later use.

In 1956, the Department of Defense initiated a broad program of free-radicals research at NBS. It helped to support the work of more than 30 scientists, including Broida—head of the Bureau effort, Arnold M. Bass—his deputy and frequent collaborator, and many visitors from industry and academia. Among NBS employees associated with the program were James R. McNesby, Milton D. Scheer, Ralph Klein, Louis J. Schoen, Jerome Kruger, and Robert W. Zwanzig.

For three years, the group engaged in free-ranging studies of energetic materials and reactions. Although no "superfuel" for rockets materialized as a result of the program, nearly 100 scientific papers documented advances in materials and techniques brought forth during its existence.

The Free Radicals program was formally discontinued in July 1959 and its remaining staff members were integrated into a new Physical Chemistry Division in 1960, under the leadership of Merrill B. Wallenstein.

After the formal demise of the Free Radicals program, two Bureau scientists who continued studies of the chemistry of excited molecules were Dolphus E. Milligan and Marilyn E. Jacox. The two had met and collaborated on free-radicals research at the Mellon Institute of Industrial Research in Pittsburgh in 1958. Separately and more or less coincidentally, both joined the NBS staff.

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[195] G. J. Lutz, "Determination of oxygen in sodium by photon activation analysis," *Anal. Chem.* **42**, No. 4, 531-532 (1970).

[196] G. J. Lutz and L. W. Masters, "Determination of carbon in high purity metals by photon activation analysis," *Anal. Chem.* **42**, No. 8, (1970).

[197] H. P. Broida and J. R. Pellam, "Phosphorescence of Atoms and Molecules of Solid Nitrogen at 4.2 K," *Phys. Rev.* **95**, 845-846 (1954).

Milligan had learned of matrix-isolation spectroscopy as a student of George Pimentel at the University of California at Berkeley. Much of this work involved holding marginally stable, metastable, or unstable chemical species in a low-temperature matrix to stop the chemical reactions that ordinarily would prevent their observation.[198]

Jacox joined the Bureau staff in November 1962. When Milligan joined NBS in 1963, they renewed their collaboration on free radicals made from various small molecules, eventually using a Beckman IR9 spectrometer[199] to study the infrared spectra of a large variety of substances. Among these were: CF_2, CN_2, HNC, HCO, FCO, CF_3, ClCO, NCN, CH_3, SiF_3, $SiCl_2$, and $SiCl_3$.[200]

Vacuum-ultraviolet photolysis techniques used in the Photochemistry Section (see Ch. 4) made possible the study of the last four species in the list given in the previous paragraph. The same techniques permitted the study of molecular cations and anions. The first of these was C_2^-,[201] which was also the first molecular anion to yield a gas-phase electronic spectrum. Another important anion identified in this program was O_3^-.[202]

Jacox and Milligan also learned to make and identify other anions and cations produced by their matrix-isolation techniques.

In 1966, Milligan was awarded the prestigious Arturo Miolati Prize from the University of Padua, Italy. In 1970, Milligan and Jacox jointly received the Department of Commerce Gold Medal award for their work. In 1973, Jacox received the Federal Women's Award. In the same year, she and Milligan shared the NBS Stratton award for "their determination of the spectroscopic properties of charged radical ions in inert matrices at low temperatures, and the elucidation of their structures and chemical reactivities."

Radiation sources in the vacuum-ultraviolet range were the specialty of other groups that also were interested in chemically reactive species. One group was led by Pierre Ausloos. Hideo Okabe and James McNesby had similar interests. Their work is described in some detail in Ch. 4.

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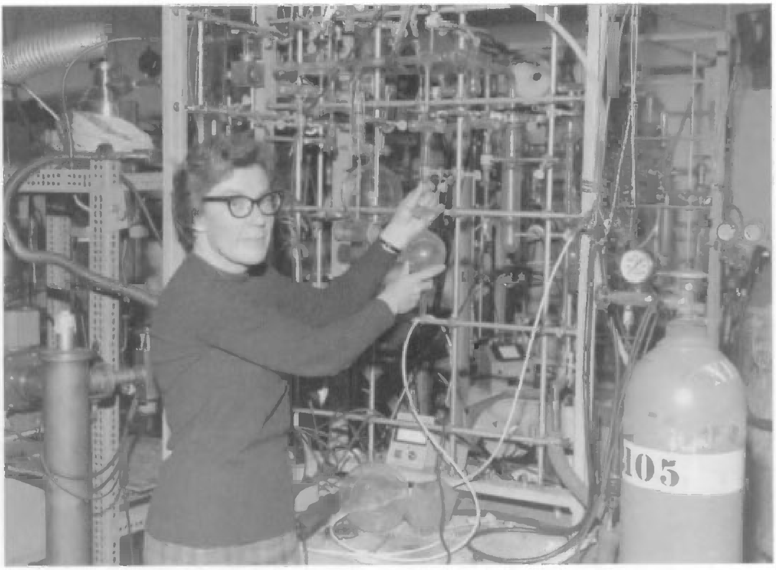
[198] Oral History, Marilyn Jacox, 11 February, 1998.

[199] According to Jacox (Oral History, February 11, 1998) a great advantage of this instrument was that its range extended from 4000 cm^{-1} to 400 cm^{-1}.

[200] D. E. Milligan and M. E. Jacox, "Infrared and ultraviolet spectroscopic studies of a number of small free radicals and molecular ions in a matrix environment," *Advances in High Temperature Chemistry* **4** (New York: Academic Press, 1971) Chapter 1, pp. 1-24. See also D. E. Milligan and M. E. Jacox, "Infrared and ultraviolet spectroscopic studies of free radicals and molecular ions isolated in inert solid matrices," *Molecular Spectroscopy;* Modern Research (New York: Academic Press, 1972) pp. 259-286.

[201] D. E. Milligan and M. E. Jacox, "Studies of the photoproduction of electrons in inert solid matrices. The electronic spectrum of the species C_2^-," *J. Chem. Phys.* **51**, No. 5, 1952-1955 (1969).

[202] M. E. Jacox and D. E. Milligan, "Vibrational and electronic spectra of the O_3^- anion isolated in an argon matrix," *J. Mol. Spectrosc.* **43**, No. 1, 148-167 (1972).



Marilyn Jacox adjusted the high-vacuum gas-handling system used in matrix isolation studies of reactive molecules.

During the same period, Henry M. Rosenstock, Vernon H. Dibeler, James A. Walker, and Kenneth E. McCulloh utilized photoionization and mass analysis to derive dissociation energies of excited species.[203]

Olefin Reactions at Low Temperatures

An olefin—also called an alkene—is an unsaturated hydrocarbon, i.e., it has one or more doubly-bonded carbon atom pairs. The simplest examples of this type of molecule are ethylene, whose formula can be written semi-graphically as $H_2C = CH_2$; propene, $H_3C{-}CH = CH_2$; 1-butene, $H_3C{-}CH_2{-}CH = CH_2$; 2-butene, $H_3C{-}CH = CH{-}CH_3$; and 1,3-butadiene, $H_2C = CH{-}CH = CH_2$. The olefins became interesting to chemists before World War II as the nature of free radicals became known.[204] It was hoped that, by studying the reactions of olefins, insight could be gathered into the mechanisms of chemical reactions and into the kinetic properties of the reactions.

[203] V. H. Dibeler, J. A. Walker, K. E. McCulloh, and Henry M. Rosenstock, "Effect of hot bands on the ionization threshold of some diatomic halogen molecules," *Intern. J. Mass Spectrom. Ion Phys.* **7**, 209-219 (1971). See also V. H. Dibeler, J. A. Walker, and K. E. McCulloh, "Dissociation energy of fluorine," Letter to the Editor, *J. Chem. Phys.* **50**, No. 10, 4592-4593 (1969).

[204] See, for example, Walter J. Moore, Jr. and Hugh S. Taylor, "The mercury photosensitized hydrogenation of ethylene, propylene, and n-butylene," *J. Chem. Phys.* **8**, 504 (1940).

In March 1966, Dolphus Milligan was presented the Arturo Miolati award by the Italian Ambassador to the United States at the Italian Embassy in Washington, while his children, his wife (left), Marilyn Jacox (second adult from left), Allen Astin (center), and others looked on.

Ralph Klein, Milton D. Scheer, and Richard D. Kelley of the Physical Chemistry Division, as part of the Bureau's Free Radical Program, began study of the hydrogenation of olefins at low temperatures during the early 1960s.[205] The use of low temperatures was commenced in order to slow or eliminate some of the many reactions which could so complicate the experiments as to defy analysis. Another tool used by Klein, Scheer and Kelley was a matrix of inert molecules (typically propane) to dilute the active olefin radicals.

[205] Ralph Klein and Milton D. Scheer, "Matrix effects in the gaseous hydrogen atom—olefin diffusion model," *J. Phys. Chem.* **66**, 2677 (1962). See also R. Klein, M. D. Scheer, and R. D. Kelley, "Disproportionation-combination reactions of alkyl radicals and hydrogen atoms at low temperatures," *J. Phys. Chem.* **68**, 598 (1964).

By 1970 the group began to understand some of the elementary reaction steps that occurred in this type of system and experimented with atomic oxygen and with deuterium as alternative reactants.[206] By analyzing the products that resulted from the various reactions, they could speculate on the reactive pathways followed by the olefin radicals. Mainly, these took the form of disproportionation reactions—such as the formation of normal butane and 2-butene from the hydrogenation of 1-butene—or of dimerization. Differences arising from the use of atomic deuterium as a reactant instead of atomic hydrogen occasionally were spectacular—changes in product concentrations by factors of as much as three, indicating the existence of a tunneling mode in these reactions. The oxygenation reactions showed direct relevance to air-pollution problems, such as the production of aldehydes and ketones, well-known as eye irritants in smog.

During this time period, Klein also studied chemisorption and decomposition of reactive species on metals. Ruthenium was a favorite target, field emission microscopy a favorite tool. Over the next decade, Klein teamed with John T. Yates, Jr., Allan J. Melmed, James W. Little, Theodore Madey, and Arnold Shih, a collaborator from the U.S. Naval Research Laboratory, to elucidate the activity of such molecules as nitric oxide. The scientists obtained information on physisorption *vs* chemisorption, chemical binding states, and work functions.[207]

Awards For Prominent Chemists

Two prominent Bureau chemists were recognized by outside organizations for the excellence of their work during Branscomb's tenure as director.

Robert S. Tipson, a member of the NBS staff since 1957, received the 1971 Hudson Award from the American Chemical Society's Division of Carbohydrate Chemistry. Tipson, a research chemist in the Analytical Chemistry Division, was recognized internationally for his studies in carbohydrate chemistry.

Then 65 years of age, the English-born Tipson was in the midst of collaborations with colleagues Barbara F. West, Robert F. Brady, Jr., and Alex Cohen on the reactions of sulfonic esters, on acid hydrolysis of acetals, on synthesis of pentuloses, and on the preparation of D-psicose.[208]

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[206] R. Klein and M. D. Scheer, "Reaction of O(^{3}P) with 2-methyl-2-pentene at low temperatures and its implication for the transition state," *J. Phys. Chem.* **73**, 1598 (1969). See also R. Klein and M. D. Scheer, "Addition of oxygen atoms to olefins at low temperatures. IV. Rearrangements." *J. Phys. Chem.* **74**, 613 (1970). For a brief summary of this work, see the *NBS Technical News Bulletin* **54**, No. 6, 119-120, June 1970.

[207] See, for example, Ralph Klein and Arnold Shih, "Chemisorption and decomposition of nitric oxide on ruthenium," *Surface Science* **69**, pp. 403-427 (1977).

[208] R. S. Tipson and A. Cohen, "Reaction of some sulfonic esters of D-mannitol with methoxide: synthesis of 2,3:4,5-dianhydro-D-iditol," *Carbohydrate Res.* **7**, 232-243 (1968). See also R. S. Tipson, B. F. West, and R. F. Brady, Jr., "Acid-catalyzed hydrolysis of isopropylidene acetals of some 2-pentuloses and 2-hexuloses," *Carbohydrate Res.* **10**, 181-183 (1969). See also R. S. Tipson and R. F. Brady, Jr., "Synthesis of the two D-2-pentuloses. New derivatives of D-erythro-pentulose," *Carbohydrate Res.* **10**, 549-563 (1969). See also R. S. Tipson, R. F. Brady, Jr., and B. F. West, "Cyclic acetals of ketoses, Part IV. Re-investigation of the oxidation of 1,2:4,5-Di-O-isopropylidene-β-D-fructopyranose with methyl sulfoxide-acetic anhydride," *Carbohydrate Res.* **16**, 383-393 (1971).

Ralph Klein (seated) and Arnold Shih made observations on the desorption and decomposition of nitric oxide on a ruthenium surface.

John K. Taylor, a member of the Analytical Chemistry Division, continued to receive the plaudits of his professional peers. He was presented the 1972 Professional Service Award of Alpha Chi Sigma for his long, continuous service to chemistry.

Taylor was a Washington, DC, native who had joined NBS as a laboratory assistant upon graduation from high school in 1929. While a Bureau employee, Taylor earned a B.S. degree in chemistry from George Washington University and M.S. and Ph.D. degrees in chemistry from the University of Maryland. In the meantime, he undertook ever more ambitious and meaningful laboratory investigations in the fields of analytical and electrochemistry. He wrote more than 200 scientific articles and wrote or edited seven books on chemistry or quality assurance—a field of work that felt his impact during his later years.

By the time he retired in 1986, Taylor's excellent work and longevity had been recognized by President Ronald Reagan. Taylor received many awards. Among them were the DC Education Association Award in 1965; the Joint Board of Science Education Award in 1966; the Department of Commerce Gold Medal in 1967; the Honor Scroll of the American Institute of Chemists in 1968; and the Service Award of the Chemical Society of Washington in 1969.

Cryogenic Liquids, Then and Now

We noted in Chapter 1 that the Cryogenics Laboratory at NBS/Boulder came into being to supply liquid hydrogen and liquid deuterium for testing and production of thermonuclear weapons. With the successful tests of the thermonuclear-explosion concept in 1951 and 1952, the value of the Cryogenics Laboratory was clear. In 1953, the Department of Commerce Gold Medal award for "The design, construction, and operation of large and unique hydrogen and nitrogen liquefiers" was given jointly to Paul G. Baird, Bascom W. Birmingham, Ferdinand G. Brickwedde, Dudley B. Chelton, George A. Freeman, William F. Goddard, Victor J. Johnson, Richard Kropschot, Robert L. Powell, Russell B. Scott, and Peter C. Van der Arend.

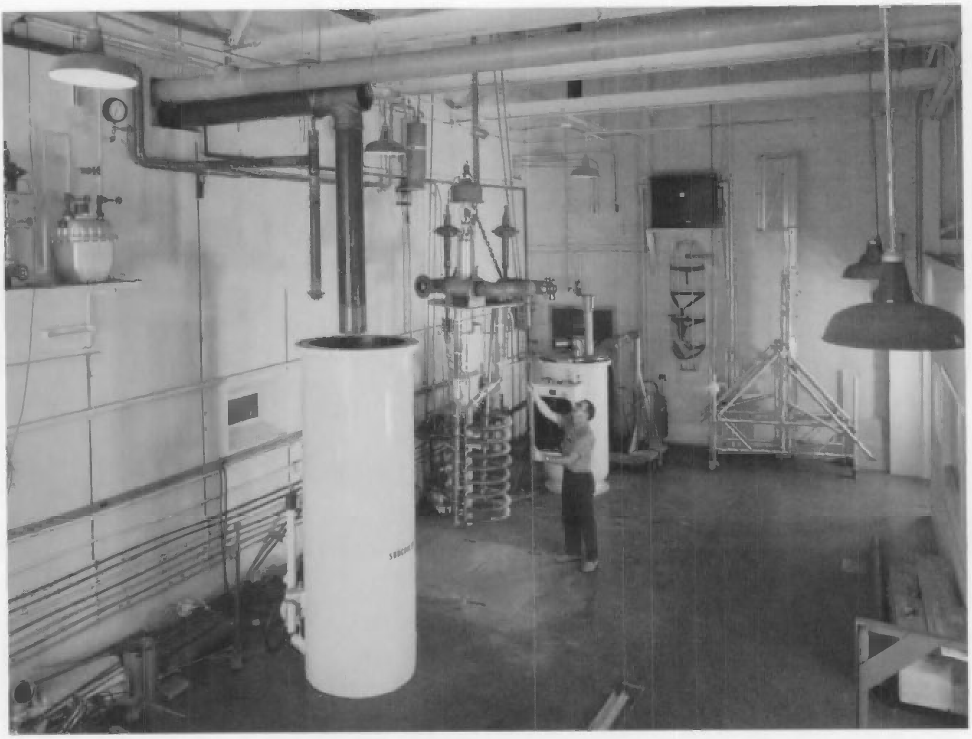
The special-weapons work did not spell the end of the laboratory's work with large quantities of liquid cryogens, however—far from it. During the 1950s the staff also was asked to assist scientists at the University of California Radiation Laboratory (UCRL) in the design and construction of an unusually large hydrogen bubble chamber for use in tracking sub-atomic particles emanating from experiments in the accelerators there. In the process, the Boulder group—Bascom W. Birmingham, Dudley B. Chelton, and Douglas B. Mann—spent considerable time in teaching the UC scientists how to handle the explosive liquid.

The effort spent at UCRL paid off in a big way during the winter of 1968–1969, when Luis W. Alvarez was awarded the 1968 Nobel Prize in physics in recognition of his discoveries in the field of elementary particles. His work depended heavily upon the use of the hydrogen bubble chamber that Birmingham, Chelton, and Mann had helped bring to reality. Alvarez gave full credit to the Bureau scientists for their contributions to his work.

One of the outstanding problems in the cryogenics industry was that of accurately metering the transfer of cryogenic liquids. Cryogens constituted a valuable component of U.S. industrial production—about $500 million in 1970, expected to triple by 1975. So it was with great enthusiasm that the Compressed Gas Association and officials of the California Weights and Measures Department teamed with members of the Boulder Cryogenic Engineering Division to establish a flowmetering and flow research facility at the Boulder laboratory of NBS.

It might have seemed a simple problem to meter the flow of, say, liquid nitrogen. After all, one could readily ascertain the amount of gasoline pumped into an automobile tank to two decimal places, using pumps certified by the weights and measures officials of any of the United States. However, the extreme cold generated in the metering equipment and the significant changes in density of the cryogens with substantial changes in temperature or pressure interfered considerably with the accuracy of cryogen deliveries.

The state of California sought in 1967 to create a code for cryogenic flowmetering, with an accuracy goal no worse than ± 3 %. NBS efforts to participate in the technical aspects of the project foundered on the shoals of insufficient funding at that time, but the vocal support of the industry gradually raised the priority of the task for the Bureau. Careful plans were prepared for the eventual creation of an NBS cryogenic flowmetering facility. Douglas B. Mann was placed in charge of the project.



James Brennan assembled a liquid nitrogen heat exchanger at the NBS cryogenic flowmetering and flow research facility in Boulder, Colorado.

In 1970 the facility completed its first year of operation.[209] A closed flow loop permitted the continuous operation of flowmeters under test, to monitor both accuracy and wear. The system could be operated isothermally at any temperature from 63 K to 115 K, at any pressure from 7 kPa to 2000 kPa, and at flow rates from 76 L/min to 760 L/min.

One of the unique features of the loop was a flow diverter valve. It proved necessary for the NBS staff to design and manufacture a suitable valve, since none available commercially could promise the leak-proof service needed to ensure accuracy. Another component unique to the project was a weigh tank used to monitor the amount of cryogen delivered within a given time through the test meter.

As the facility began its service, Mann contemplated needed improvements, including the ability to directly measure quantities of liquid oxygen and the development of a transfer standard for use in the field. But the basic capability, a cryogenic flowmetering facility, was a reality.

[209] "Cryogenic flowmetering at NBS," *NBS Technical News Bulletin* 54, No. 8, pp. 167-169, August 1970.

Protecting the Consumer

Among the many consumer-oriented programs at NBS, two of the most visible ones were in law enforcement and vehicle safety. We note in this section the progress in each of these during the Branscomb years.

Standards For Law Enforcement

In 1967, the President's Commission on Law Enforcement and Administration of Justice took notice of the growing trend towards lawlessness and disorder on American streets in a report entitled *The Challenge of Crime in a Free Society.* The Commission urged that a Federal agency be assigned to "coordinate the establishment of standards for equipment to be used by criminal-justice agencies, and to provide those agencies with technical assistance." Perhaps remembering the work of Wilmer Souder, an NBS physicist who long ago had served as an expert analyst of ransom notes, inks, bullet fragments, and other forensic evidence, the writers named the Bureau as a suitable place for the job. Their faith was justified.

On June 19, 1968, the 90th Congress passed the *Omnibus Crime Control and Safe Streets Act of 1968 (Public Law 90-351).* Its preamble stated:

> Congress finds that the high incidence of crime in the United States threatens the peace, security, and general welfare of the Nation and its citizens. To prevent crime and to ensure the greater safety of the people, law enforcement efforts must be better coordinated, intensified, and made more effective at all levels of government.

The text of the Act made clear its aim to strengthen state and local law-enforcement capabilities. This goal would be accomplished by a team centered in the Department of Justice, where a Law Enforcement Assistance Administration (LEAA) would be created. As part of the LEAA, there would be a National Institute for Law Enforcement and Criminal Justice (NILECJ); its job would be to activate a program of research and development to give state and local police the tools they needed to fight crime more effectively.

During its first year of existence, NILECJ—at the suggestion of the Law Enforcement Commission—turned to NBS for help. Once ground rules for funding, personnel, and relationships were worked out, a memorandum of understanding was signed by the two organizations. Irving Slott, Acting Director of the LEAA, transferred $400,000 to the Bureau to fund a new entity for NBS, the Law Enforcement Standards Laboratory.[210]

Paul J. Brown, experienced in the creation of interdepartmental entities,[211] was named the first Director of LESL. Within a year, Richard B. Morrison succeeded him at that position.

[210] Letter from Irving Slott to Lewis Branscomb, December 22, 1970; RHA; Director's Office; Box 390; Folder January 1-31, 1971.

[211] Brown had earlier helped organize the Office of Vehicle Systems Research to work with the Department of Transportation.

LESL quickly found flaws in the way that state and local police armed and equipped themselves. In the absence of national standards for equipment, police groups tended to copy equipment specifications from other departments or to make use of sales literature in their purchases. Accordingly, LESL assigned its staff to develop standards programs in several areas:

- Vehicle standards, led by Richard Morrison, to consider type of terrain, climate, type of use, steering, brakes, suspension, tires, engines, equipment-carrying capability, stability, durability, safety, and comfort.
- Communications equipment, led by Marshall J. Treado, to consider portable radios and power supplies, voice scramblers, digital systems, and automatic vehicle locators.
- Security systems, led by Marshall Isler, to consider false-alarm rates (estimated by some departments to be as high as 90 %), alarm sensors (sound, vibration, heat, motion), surveillance, locks, protective room equipment, safes, and night-vision devices.
- Concealed-object detectors, led by Robert Mills, to consider detection methods for metallic weapons, narcotics, and explosives.
- Protective equipment and clothing, led by Jacob J. Diamond, to consider guarding against injury from bullets, bombs, fire, thrown missiles, tear gas, carbon monoxide, vehicles, rain, and snow. Items specific to certain conditions were investigated, including body armor, helmets, face shields, breathing masks, ear-muffs, seat belts, and apparel to resist damage from radiation, heat, flame, chemicals, rain, and cold, while permitting needed range of motion.
- Emergency equipment, led by Avery T. Horton, to consider first aid equipment, emergency procedures, and the standardization of emergency-identifying flashing lights.
- Police weapons, led by Jacob Diamond, with virtually all preliminary developments—for both lethal and non-lethal weapons—to be performed by outside contractors.
- Building systems, led by Avery T. Horton, to consider the design and evaluation of all law-enforcement buildings, construction materials, furnishings, and other building equipment and supplies.[212]

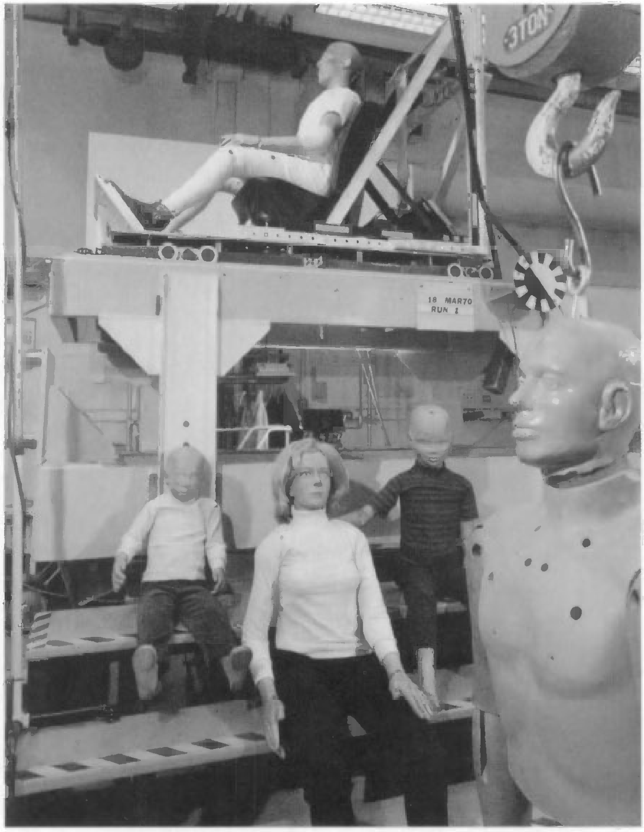
The new-born LESL did not build its own laboratory at the Bureau, but purchased research and development from existing NBS groups or from outside contractors. Thus the LESL staff became "matrix"-type program managers. NBS divisions involved in the work included electromagnetics, analytic chemistry, applied radiation, mechanics, heat, building research, technical analysis, measurement engineering, and electronic technology.

[212] "NBS Works with Justice Department on Modern Law Enforcement Standards," *NBS Technical News Bulletin* **56**, June 1972, pp. 139-141, 149.

Automobile Crash Testing

In 1969, the program of the Bureau's Office of Vehicle Systems Research was continued by agreement between the Department of Commerce and the Department of Transportation. The National Highway Safety Bureau was glad to have access to the objectivity and expertise of NBS in the field of auto safety.

One project, reported by OVSR's Richard F. Chandler and Robert A. Christian, detailed problems inherent in simulating the effects of automobile crashes on human occupants.[213] They noted that, unlike standard auto design—which relies heavily on anthropomorphic data obtained from live subjects—crash testing utilized dummies or cadavers.



A family of dummies—a 217-pound male, a 105-pound female, and their children weighing 31 and 49 pounds—awaited a sled ride at the NBS that would subject them to the same force as a crashing car. This research on occupant restraint systems was sponsored by the Department of Transportation.

[213] R. F. Chandler and R. A. Christian, "Crash testing of humans in automobile seats," pp. 112-132 in *Proc. Society of Automotive Engineers Safety Conf., May 13-15, 1970, Detroit* (New York: SAE, June 1970).

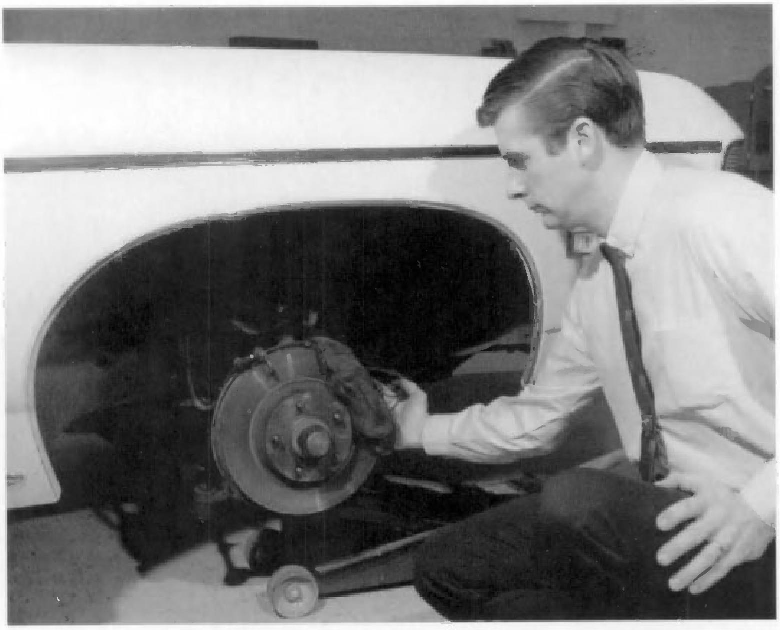
To augment the meager store of data on human response to automobile crashes, the Bureau scientists initiated a "crash" program with colleagues operating the Daisy Decelerator at Holloman Air Force Base. The testing included 32 trials in which human subjects participated in simulated crash decelerations while sitting in production-model auto seats and wearing restraints of various types. By repeating the tests with dummies, they were able to relate the more extensive data obtained with the use of dummies to actual human responses.

A critical part of automobile-crash safety was the effectiveness of seat belts. Personnel of the OVSR used a variety of test equipment to evaluate the breaking strength of manufacturer-installed belts, as well as their resistance to abrasive wear in use.

Dorian Sanders of the NBS Office of Vehicle Systems Research positioned seatbelt webbing in a tensile test machine. The resulting data was used to update Federal automotive standards in the early 1970s.

Pushing on the Brakes

The then-current *Federal Motor Vehicle Safety Standard* for braking force by a driver called for the exertion of 200 pounds on the automobile brake pedal. Curious about the difference in strength between men and women, Richard W. Radlinski and James I. Price tested 105 women, using actual automobiles as the test stations. They found that fewer than half of the women could actually meet the force standard, clearly demonstrating a need for re-evaluation of the Federal code.[214]

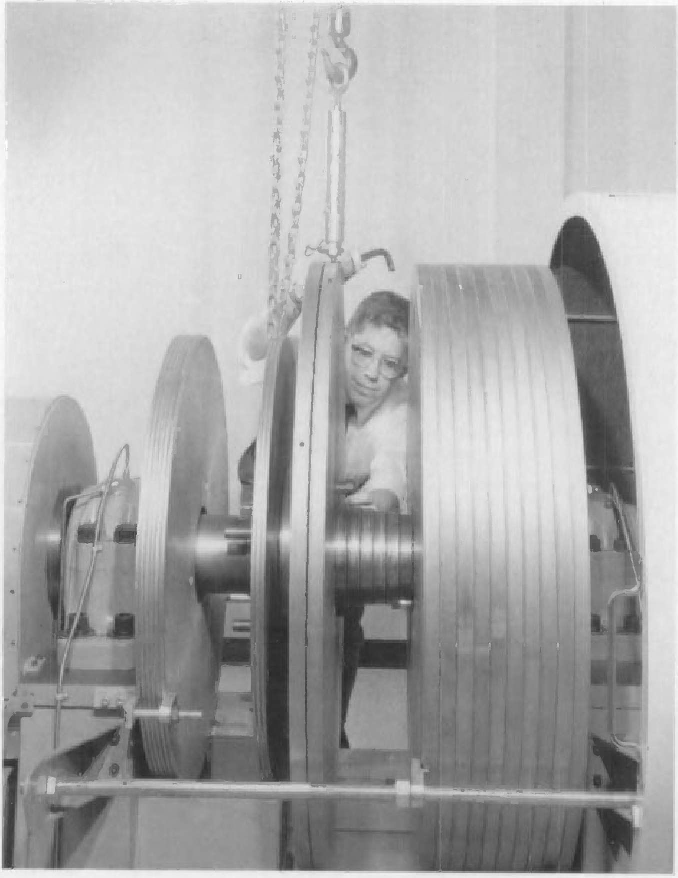


Richard Radlinski of the NBS Office of Vehicle Systems Research checked the leads to a temperature sensor placed on automobile disc brakes.

With Robert J. Forthofer and Jack L. Harvey, Radlinski evaluated the effect of water on the performance of brake fluids.[215] They found that most brake systems took on road water through connecting hoses, causing a reduction in the temperature at which vapor lock took place and increasing the fluid density at temperatures near the water freezing point. They obtained data on water-contaminated brake fluids under various conditions.

[214] R. W. Radlinski and J. I. Price, "The brake pedal force capability of adult females," *NBS Tech. Note 557*, 25 pp., October 1970. See also "Panic stops: are women strong enough?" *NBS Technical News Bulletin*, January 1971, pp. 15-16.

[215] R. W. Radlinski, R. J. Forthofer and J. L. Harvey, "Operating performance of motor vehicle braking systems as affected by fluid water content," *Proc. Society of Automotive Engineering Conf.*, pp. 1-11, Jan. 11-15, 1971.



John Preston adjusted weights on the NBS dual-end inertia dynamometer, used to study automotive braking systems in the laboratory. The machine could be set to simulate vehicles weighing from 900 to 14,000 pounds. Data obtained with the device compared well with actual road-test results.

Slippery when Wet!

Disturbed by reports of numerous wet-weather accidents occurring along the interstate highway closest to NBS,[216] the Office of Vehicle Systems Research developed a test for pavement skid resistance. Under the direction of F. Cecil Brenner, chief of the OVSR tire systems section, OVSR staff members fitted a truck to tow a test rig that was mounted on a two-wheeled trailer. Tires with known braking properties could be individually locked as the rig was driven along the "interstate" while water was sprayed on the roadway. Recording equipment provided data on the frictional force exerted on the axle of the skidding wheel.

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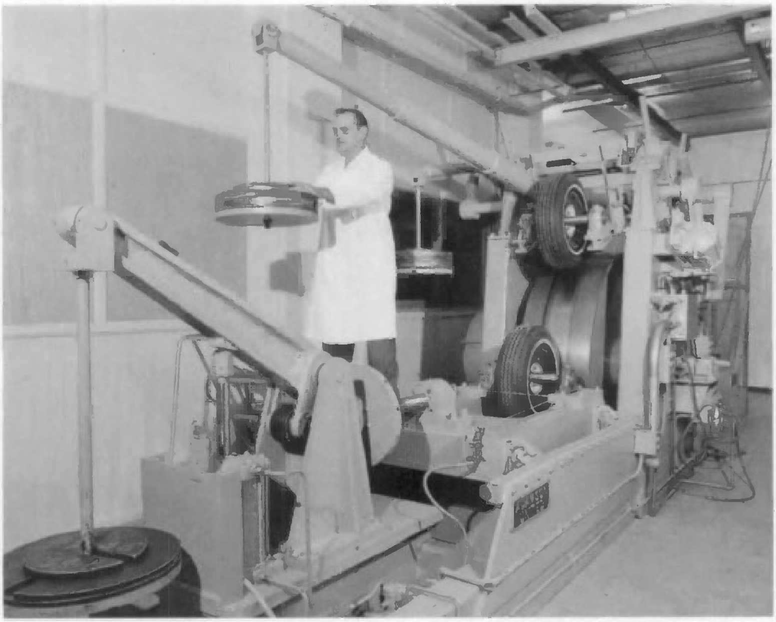
[216] More than 100 wet-weather crashes took place on Interstate 70S (later designated I-270) during 1968-69. Details of the Bureau skid program are given in "Warning—Slippery when Wet," *NBS Standard,* Vol XV, No. 1, January 1970, pp. 1, 4.

The road tests showed that the interstate road surface became unsafe in wet weather. At seven of eight test locations, the wet-highway skid resistance was below the norm even for low-speed, rural roads; at one location, the wet surface reacted as if it had been coated with ice!

Brenner ascribed the dangerous condition to the tendency of the surface—initially prepared from rough aggregates—to become smoother with use because of the "polishing" effect of traffic. In addition to its official reports on the testing, OVSR provided Bureau employees with appropriate hints to avoid commuting accidents in wet weather.

A Grading System for Tires

Systematic research on tire wear was performed by OVSR staff in order to develop a uniform and reliable grading guide. F. Cecil Brenner and Akira Kondo participated in testing tires on two road courses built in Texas. Results were obtained for some 18 different brands of commercially available passenger-car tires.[217]



Tire endurance and heat sensitivity were tested on the "NBS Wheel," a large wheel 1/300 of a mile in circumference. Dallas Rhodes positioned weights to simulate the weight of a vehicle. A similar wheel was used at the Bureau as early as 1920.

[217] F. C. Brenner and A. Kondo, "Research for a uniform quality grading system for tires. IV. Tread wear," *Rubber Chem. Technol.* **44**, No. 1, pp. 106-121, March 1971.

In a separate series of tests, Brenner and Kondo compared the mileage expectancy for front-wheel-drive automobiles and those using rear-wheel drive. They found that tires wore twice as fast if they were on the front wheels of a front-wheel-drive car as they did on the rear wheels of the same vehicle, whereas tire wear was nearly the same on both axles of rear-wheel drives. However, frequent rotation of the tires on the front-wheel-drive vehicles made them last nearly as long as tires on rear-wheel-drive cars.[218]

Teaching Computers to Serve

The first fully operational, automatic, electronic computer in the United States was the Standards Electronic Automatic Computer (SEAC), built at NBS.[219] The useful life of SEAC began in May 1950 and extended into 1964, despite its designation as an "interim" development. Because of this early experience, NBS staff members who worked on the SEAC were asked by the Bureau of the Census, the U.S. Army, and the U.S. Air Force to monitor progress on a fully automatic computer—the UNIVAC machine.[220]

As a result of assignments given to NBS by the Brooks Act (Public Law 89-306, 1965), the Bureau provided a broad range of services on the use of computers—from guidance on hardware and software standards to performing research involving computers in all sorts of projects.[221]

The work was focused in the Center for Computer Science and Technology. As we noted earlier, Director Branscomb placed Ruth M. Davis in charge of the CCST program and its staff of about 150 people. The program, already strong, continued its tradition of service under Davis until her departure from the Bureau in 1977.

Managing the UNIVAC 1108

The NBS main-frame computer, a UNIVAC 1108/418, provided workhorse service—three shifts of operators a day—to Bureau employees and to outsiders who were connected to it by telephone hookups. A typical remote-site customer, the Economic Development Administration, utilized the UNIVAC to develop a data base and data-handling procedures for several years before its own computer system became available.

[218] A. Kondo and F. C. Brenner, "Research for a uniform quality grading system for tires. VI. Comparison of the effect of front and rear wheel drive vehicles on projected tread wear of a tire," *Rubber Chem. Technol.* No. 4, pp. 960-961, September 1971.

[219] Russell A. Kirsch kindly furnished the references for this paragraph.

[220] "Computer development (SEAC and DYSEAC) at the National Bureau of Standards," *NBS Circular 551,* 1955.

[221] A useful discussion of the work of the Center for Computer Sciences and Technology during this period appears in "NBS Technical Highlights, 1970," *NBS Special Publication 340,* February 1971, pp. 174-185.

An Office of Computer Information was set up within the Center to provide a magnetic-tape-based information-retrieval service, along with a database involving NBS reports, useful computer programs, and guidelines for Automatic Data Processing systems.

FIPS Publications

Federal Information Processing Standards (FIPS) were created for the benefit of the user community. These standards provided official information on computer use. They were published by the Bureau as a non-periodical series. The titles of the first ten FIPS publications give an idea of the topics treated by the standards:

- FIPS PUB 0: General Description of the Federal Information Processing Standards Register;
- FIPS PUB 1: Code for Information Exchange.
- FIPS PUB 2: Perforated Tape Code for Information Exchange.
- FIPS PUB 3: Recorded Magnetic Tape for Information Exchange.
- FIPS PUB 4: Calendar Date.
- FIPS PUB 5: States of the United States.
- FIPS PUB 6: Counties of the States of the United States.
- FIPS PUB 7: Implementation of the Code for Information Interchange and Related Media Standards.
- FIPS PUB 8: Metropolitan Statistical Areas.
- FIPS PUB 9: Congressional Districts of the United States.

As of early 1971, another half-dozen standards—on bit sequencing, character structure, and other details of computing practice—were awaiting approval at the Office of Management and Budget. Most of these were written by Harry S. White, Jr.

Computer Hardware and Software

A new Standard Reference Material, SRM 3200, provided magnetic tape for use in evaluating the performance of magnetic tape produced by various industrial organizations. The standard was developed by Sidney B. Geller of the CCST along with a tape-evaluation system that could be used in calibration.[222] An updated version of the system was presented by NBS to the Magnetic Surfaces Laboratory of the General Services Administration to be used in governmental acceptance testing.

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[222] S. B. Geller, "Calibration of NBS secondary standard magnetic tape (computer amplitude reference) SRM 3200 using the reference tape amplitude measurement 'Process A' Model II," *NBS Special Publication 260-29*, 57 pp., June 1971.

Consultations

Several CCST staff members were involved essentially full-time in providing consulting services to NBS and to other government agencies. Some of the assistance took the form of responses to telephoned requests for help; much of it, however, involved long-range projects intended to develop specialized computer systems. Automation of data acquisition in Bureau scientific laboratories was a prime need, both to save valuable time for the scientists and their assistants and to make possible the acquisition of data beyond the capability of manual dexterity. As smaller, more powerful individual computers became available to Bureau staff members, automatic data acquisition became both spectacular in its sophistication and routine in its ubiquity.

An example of the marriage of computers to laboratory equipment was given in 1969 by Philip G. Stein of the Information Processing Division. Collaborating with Lewis Lipkin and Howard Shapiro, both staff members of the National Institutes of Health, Stein linked an optical microscope with an image-plane scanner, a motor-driven stage and a general-purpose computer. Stein "taught" the computer to move the microscope stage in such a way as to scan an image in the *x-y* plane, then repetitively at successive values in the vertical, or *z*, direction. This process produced a three-dimensional image of the subject material, allowing a whole variety of computer-controlled operations.[223]

Phillip Stein of the NBS Center for Computer Science and Technology viewed a slide through a computer-controlled microscope that he developed in collaboration with the National Institutes of Health in 1969.

[223] P. G. Stein, L. E. Lipkin, and H. M. Shapiro, "Spectre II: General-purpose microscope input for a computer," *Science* **166**, pp. 328-333 (1969).

In exploratory efforts to expand the capabilities of computers in the laboratory, the CCST initiated measurements of the performance of remote-access systems, first in a time-sharing mode with a large central unit, then with smaller, personal systems. Center employees also designed data-acquisition and filing systems, interactive programs, and graphics displays for the use of computer-illiterate personnel.

Superconductivity, a Versatile Property

Superconductivity, a state of matter that was unknown at the time of the Bureau's founding (the property was discovered in the laboratory of H. Kamerlingh Onnes in Leiden, The Netherlands, in 1911), began to enter into the language of NBS standards and instrumentation during this period. A few examples illustrate the usefulness of this phenomenon in Bureau projects.

Superconductors, Josephson Junctions, and the Volt Standard

Two-layer junctions formed of two superconducting films separated by a thin insulating layer behave according to equations put forward by Brian Josephson in 1962.[224] Shortly after Josephson's predictions, "Josephson effects" were found experimentally; in the course of studying the sometimes complicated current-voltage characteristics of Josephson junctions, properties of distinct utility to NBS goals appeared.[225]

One of the properties of Josephson junctions that interested the Bureau's Electricity Division was their ability to provide voltage references that appeared to be extremely stable. In 1967, Barry N. Taylor, then at the RCA Laboratories, and his colleagues W. H. Parker, D. N. Langenberg, and A. Denenstein of the University of Pennsylvania called attention to the limited accuracy of the chemical cell used to maintain the standard of electromagnetic force, and postulated a new voltage standard based upon the ac Josephson effect.[226] A tendency of the cell voltage to change slowly with time made the maintenance of a standard of emf into a challenging task indeed—it required careful storage and handling and frequent intercomparisons among a group of cells.

The authors tested the idea of a new voltage standard with Josephson junctions composed of crossed strips of tin, separated by a thin tin oxide layer; crossed strips of lead, separated by a thin lead oxide layer; combinations of lead and tin strips, again separated by oxide layers; and various types of "point contacts," similar in configuration to a pencil-point pressed against a solid block. All of the junctions obeyed one Josephson relation involving microwave radiation and voltage—the ratio of the microwave frequency to the voltage was always equal to the constant quantity $2e/h$, where e is the elementary charge (the absolute value of the charge on the electron)

[224] B. Josephson, *Phys Lett.* **1**, 251 (1962).

[225] See, for example, Vladimir Z. Kresin and Stuart A. Wolf, *Fundamentals of Superconductivity,* (New York: Plenum Press, 1990), Ch. 12.

[226] B. N. Taylor, W. H. Parker, D. N. Langenberg, and A. Denenstein, "On the use of the ac Josephson effect to maintain standards of electromotive force," *Metrologia* **3**, No. 4, 89-98 (1967).

and h is Planck's constant. They found results that were consistent within the 4 ppm uncertainty limitation imposed by the reference voltage cells. Better accuracy was not possible at that time because of the uncertainty (about 30 ppm) with which the ratio e/h was known.

By 1970, Taylor was an NBS employee—Chief of the Absolute Electrical Measurements Section of the Bureau's Electricity Division. He was beginning a robust Bureau career in the study of precision measurement and fundamental constants. In the same year, Forest K. Harris, the former section chief, Howland A. Fowler, and P. Thomas Olsen unveiled a new type of potentiometer built especially to compare voltages obtained from standard chemical cells (about 1 V) with voltage signals generated by Josephson junctions (a few millivolts).[227] The new instrument was capable of comparing dc voltage signals in the range 2 mV to 10 mV against standard-cell voltages with uncertainties of only 0.1 ppm.[228]

Comparatively ordinary superconducting tunnel junctions, prepared in a manner similar to Josephson junctions, were shown to provide reproducible voltage signals when maintained at a fixed temperature, although the magnitude of the voltage signals could not be calculated by the Josephson relations. Thomas F. Finnegan, a Bureau postdoctoral research associate, and A. Denenstein suggested that the inconveniently small voltages (about 2 Mv) generated by Josephson junctions could be overcome by the use of multiple, series-connected junctions.[229] Their ideas were later improved at NBS by the use of multiple Josephson junctions.

By the end of 1972, the uncertainty in values of $2e/h$, measured in terms of the laboratory unit of voltage at NBS, at the National Standards Laboratory in Australia, at the National Physical Laboratory in England, and at other national laboratories, reached a low of 0.1 ppm.[230]

Thermometry with Superconductors

Random noise in electrical circuits, known as Johnson noise, arose because the electrons in the circuit were thermally excited in a random way. For this reason, many scientists used measurements of Johnson noise to determine temperature. In principle, the noise voltage depended directly upon the resistance of a circuit element and upon its temperature. Success in such experiments usually depended upon the expenditure of great effort to exclude from the measurements all sources of electrical noise of the non-Johnson variety; these were many and pervasive.

[227] F. K. Harris, H. A. Fowler, and P. T. Olsen, "Accurate Hamon-pair potentiometer for Josephson frequency-to-voltage measurements," *Metrologia* **6**, No. 4, 134-142 (1970).

[228] "Accurate measurements of Josephson junction voltage," *NBS Tech. News Bull.*, January 1971, p. 3.

[229] T. F. Finnegan and A. Denenstein, "A new transfer and maintenance voltage standard using superconducting tunnel junctions," *Metrologia* **7**, No. 4, p. 167 (1971).

[230] I. K. Harvey, J. C. Macfarlane, and R. B. Frenkel, "Monitoring the NSL standard of emf using the ac Josephson effect," *Metrologia* **8**, No. 3, 114-124 (1972). See also J. C. Gallop and B. W. Petley, "A new NPL determination of $2e/h$," *Metrologia* **8**, 129-132 (1972).

It occurred to Robert A. Kamper of the NBS/Boulder Cryogenics Division that Josephson junctions might be employed as voltage-to-frequency converters to detect the Johnson noise in a resistor held at temperatures within a few thousandths of a kelvin of absolute zero.[231] The determination of temperatures in that range was a chancy undertaking. Thermal equilibrium among the various parts of an experiment could not be guaranteed, and few indeed were thermometers that could be classified as reliable in that range. Thus Kamper's idea was welcomed in the special world of ultra-low-temperature thermometry.

The Johnson noise voltage in a cold resistor could be made to appear as "jitter" in the voltage observed across the resistor when a particular current was passed through it. If a Josephson junction were to be connected across the resistor, reasoned Kamper, the voltage jitter could appear as a linewidth of the radiation emanating from the junction. Determinations of thermal-noise voltage could then be made in terms of the scatter of frequency observations, measurements capable of relatively high precision.

Recruiting his Bureau colleagues James D. Siegwarth, Raymond Radebaugh, and James E. Zimmerman, Kamper formed a group that quickly demonstrated the usefulness of the idea. They assembled an experiment involving the use of a special refrigerator that could reach temperatures below 0.02 K, a Josephson junction formed by an adjustable niobium point contact and protected from non-Johnson noise by a superconducting niobium shield, a 10^{-5} Ω resistor, and a signal-amplifying circuit that was carefully shielded against non-Johnson noise.

The group evaluated its success by comparing the temperature values determined from their Johnson noise thermometer against temperature values derived from measurements of the susceptibility of a paramagnetic salt. As the experiment was refined, the values came more nearly into agreement, eventually differing by 0.003 K at 0.020 K.[232] It was a formidable achievement.

The noise thermometry experiments of Kamper and his colleagues in Boulder were extended and perfected over a 20-year period by Robert J. Soulen, Jr. and his colleagues in Gaithersburg. This part of the story is summarized in Ch. 6.

A quite different approach to the use of superconductors for thermometry was taken by James F. Schooley, Robert J. Soulen, Jr., and George Evans. Realizing the difficulty of performing temperature measurements below 10 K—a regime in which new cryogenic technology was increasing vastly the pace of research—these Heat Division staff members prepared wire samples of purified elemental superconductors to test the sharpness and reproducibility of the transitions between the normal and the superconductive states. They found that groups of carefully prepared and annealed lead,

[231] R. A. Kamper, "Millidegree noise thermometry," *Symp. on the Physics of Superconducting Devices, Charlottesville, Virginia, 1967.*

[232] R. A. Kamper and J. E. Zimmerman, "Noise thermometry with the Josephson effect," *J. Appl. Phys.* **42**, pp. 132-136 January 1971. See also R. A. Kamper, J. D. Siegwarth, R. Radebaugh, and J. E. Zimmerman, "Observation of noise temperature in the millikelvin range," *Proc. IEEE* **59**, 1368-1369 (1971).

indium, aluminum, zinc, and cadmium samples exhibited transitions that were both sharp and reproducible at the one-millikelvin level. Furthermore, the transitions were easy to detect using readily available mutual inductance measurement techniques.[233]

Many low-temperature-laboratory scientists expressed interest in making use of the superconductors as reference points at temperatures of 7.2 K (Pb), 3.4 K (In), 1.2 K (Al), 0.85 K (Zn), and 0.5 K (Cd). The authors were thus encouraged to prepare devices that incorporated all of the elements tested.[234] When the devices proved reliable, they were incorporated into the Standard Reference Materials program as SRM 767.[235] Later on, the element niobium (superconducting transition temperature about 9.3 K) was added to the SRM 767 group.

A second device of the same type was prepared by Soulen and R. Bruce Dove to provide reference points below 0.5 K.[236] Incorporated into the devices—designated SRM 768—were the following materials: $AuAl_2$, $AuIn_2$, Be, Ir, and W. Their superconducting transitions occurred in the range 0.21 K to 0.015 K.

During the lifetime of the program, more than 100 laboratories made use of the reference devices. An interim low-temperature scale, designated by the international Consultative Committee for Thermometry as the 1976 Provisional 0.5 K to 30 K Temperature Scale, incorporated the NBS SRM 767 devices to define five of the eleven scale reference temperatures.

Fishing for Low-Level Electromagnetic Measurements with SQUID

The idea of using Josephson junctions to detect and measure very small electrical currents and magnetic fields was an attractive one. Development of such new instruments was inevitable once it was discovered that the critical current in a superconducting ring closed by a Josephson junction behaved in a periodic way as a magnetic field threading the ring was increased or decreased.

While he was still working at the Ford Motor Company Scientific Laboratory with A. H. Silver, James E. Zimmerman participated in experiments which demonstrated some of the features of such devices.[237] With colleagues David Cohen of MIT and

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[233] J. F. Schooley and R. J. Soulen, Jr., "Superconductive transitions suitable as thermometric fixed points," *Proc. XII Conf. on Low Temperature Physics, Kyoto, Japan, September 3-10, 1970*, E. Kanda, Editor, (Tokyo: Keigaku Publishing Co., 1971) pp. 833-834. See also "Superconductive transitions suitable for thermometric fixed points," *NBS Technical News Bulletin*, February 1971, pp. 39, 58.

[234] J. F. Schooley and R. J. Soulen, Jr., "Thermometric fixed points using superconductivity," *Advan. in Cryog. Eng.* **17**, 192-198 (1972).

[235] J. F. Schooley, R. J. Soulen, Jr., and G. A. Evans, Jr., "Standard reference materials: preparation and use of superconductive fixed point devices, SRM 767," *NBS Special Publication 260-44*, 35 pp., December 1972.

[236] R. J. Soulen, Jr. and R. B. Dove, "Standard reference materials: SRM 768: Temperature reference standard for use below 0.5 K," *NBS Special Publication 260-62*, 47 pp., April 1979.

[237] A. H. Silver and J. E. Zimmerman, "Quantum states and transitions in weakly connected superconducting rings," *Phys. Rev.* **157**, No. 2, pp. 317-341 (1967).

Edgar Edelsack of the Office of Naval Research, Zimmerman developed a magneto-cardiographic instrument using these principles.[238] Recorded heartbeats (in one case, Zimmerman's own) were obtained in a shielded room by placing the subject's torso near the tip of the cryostat containing the detector circuitry. The recordings were clear and readily interpretable. The device portended a wholly new medical application for superconducting detectors.[239]

By mid-1970, Zimmerman was constructing weakly connected superconducting rings and investigating their properties as an employee of the Bureau's Cryogenics Division in Boulder. In these experiments he participated with a group that included Robert Kamper, L.O. Mullen, Donald B. Sullivan, Nolan V. Frederick, and Michael B. Simmonds.[240]

Detecting High-Frequency Radiation with the Josephson Effect

How high in frequency could a Josephson junction respond to radiation? This was more than an academic exercise for a group of scientists in the Time and Frequency Division in Boulder. The group included Donald G. McDonald, Kenneth M. Evenson, Joseph S. Wells and J. D. Cupp. They were interested in the possibility of measuring the output of lasers. They found that a point-contact Josephson junction would respond to radiation of frequency 2.5 THz, a factor of three higher than previously observed by direct irradiation. By using harmonic generation, the upper limit could be extended at least to 8 THz.[241]

Building Research

The Bureau's building research program addressed a diverse range of problems, many of them involving travel to the scenes of disasters. The following accounts provide a sampling of these projects.

Buildings Versus Mother Nature

On February 9, 1971, a medium-strength earthquake struck the San Fernando valley in California. At 6.6 on the Richter scale, it was strong, though nowhere near the record. Yet there was severe damage: 64 people killed, buildings and highway

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[238] D. Cohen, E. A. Edelsack, and J. E. Zimmerman, *Appl. Phys. Lett.* **16**, 278 (1970).

[239] J. E. Zimmerman, "Recent developments in superconducting devices," *J. Appl. Phys.* **42**, No. 1, pp. 30-37 (1971). This paper was part of the *1970 Applied Superconductivity Conference, June 15-17, 1970, Boulder;* Richard H. Kropschot of NBS Boulder was Conference Chair. See also "Superconducting device measures heartbeat magnetically," *NBS Technical News Bulletin,* April 1971, pp. 100-101. The author is grateful to Harold Weinstock of the *Air Force Office of Scientific Research* for pointing out that SQUID arrays in helmet-shaped Dewar systems were (in 1999) used to monitor brain activity, both in cognitive studies and in pathology.

[240] See D. B. Sullivan, "Superconducting Quantum Interference Devices: An operational guide for rf-biased systems," *NBS Tech. Note 629,* 40 pp., November 1972, and R. A. Kamper and D. B. Sullivan, "Developments in cryoelectronics," *NBS Tech. Note 630,* 68 pp., November 1972.

[241] D. G. McDonald, K. M. Evenson, J. S. Wells and J. D. Cupp, "High-frequency limit of the Josephson effect," *J. Appl. Phys.* **42**, No. 1, pp. 179-181, January 1971.

structures destroyed, and property loss estimated at $500 million. The White House Office of Emergency Preparedness requested that NBS send a team to evaluate the damage from the point of view of improving building codes so as to minimize losses from future quakes.

Four members of the Bureau's Building Research division, including Hai S. Lew, Edgar V. Leyendecker, and Robert D. Dikkers, reached the scene within 24 hours. They made photographic recordings of damaged homes, schools, hospitals, roadways, bridges, and other public facilities.

In some cases, the team found that local buildings had been constructed according to outdated codes, with the result that they failed under stresses that newer codes would probably have accommodated. Other buildings, such as the Veterans Hospital, had been built prior to the existence of earthquake codes. Its collapse might have been prevented had there been a mechanism to utilize existing information to reinforce it in critical areas. The team noted that important public facilities such as hospitals—four in the area were damaged so severely that they could no longer function—could be given special strengthening to reduce the chance that they would fail in future quakes. Water, sewage, gas and electric lines could similarly receive special attention.[242]

The Building Research Division was asked by the Environmental Sciences Services Administration to inspect an area near Lubbock, Texas, that was devastated by a tornado on May 11, 1970. Twenty-six people were killed by the twister; 1500 were injured and 3500 became homeless in moments. Total property damage was estimated at $200 million.

A Bureau team led by Norman F. Somes and including Robert D. Dikkers and Thomas H. Boone spent three days at the site. In June they issued a report on their findings. The highlights of the report[243] included the following:

- Most damage to the interiors of homes resulted from initial loss of the roof structures.
- Much of the damage and personal injury resulted from flying glass, wood, and masonry.
- Many mobile homes without over-the-top tiedowns were rolled, producing near-total destruction of their contents.
- Structures that stiffened building walls generally helped to preserve them in spite of the wind.

The Bureau work contributed to improved design of buildings against the forces exerted by the high winds accompanying tornadoes and hurricanes.

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[242] H. S. Lew, E. V. Leyendecker, and R. D. Dikkers, "Engineering aspects of the 1971 San Fernando earthquake," *NBS Building Science Series* **40**, 419 pp., December, 1971.

[243] "Tornado Havoc Linked to Building Elements," *NBS Standard,* Vol XV, No. 7, July 1970, pp. 4-5. See also N. F. Somes, R. D. Dikkers, and T. H. Boone, "Lubbock tornado; a survey of building damage in an urban area," *NBS Tech. Note 558,* March 1971.

A new organization concerned with wind damage was created by the U.S.-Japan Cooperative Program in Natural Resources in 1969. Edward O. Pfrang, chief of the BRD Structures Section, helped to form the U.S.-Japan Panel on Wind and Seismic Effects and served as the United States chair of the panel until 1984. Over the years, more than 1000 scientific papers were published as a result of panel meetings, data was shared on earthquakes, storm surges, and tsunamis in both countries, and co-operative testing was performed to advance the development of building-design criteria.[244]

Applying Performance Standards

The Bureau's efforts on behalf of *Project Breakthrough* took on a more substantial form early in 1971, as the first of 22 housing systems was delivered to the Building Research Division for testing and evaluation.[245] *Project Breakthrough* was a major Housing and Urban Development operation intended to create and demonstrate efficient methods using performance standards for the construction and erection of manufactured housing to alleviate a nationwide shortage of modestly priced homes.

The first module, a 20 m by 4 m by 5 m prototype built by Levitt Technology, Inc. of Kalamazoo, Michigan, was shipped by rail to the NBS Gaithersburg site. Initial tests were designed to verify that the units could be shipped by rail without damage.

The Building Research Division staff emphasized that performance criteria—a departure from the material specifications previously used in the housing industry—would be employed to decide the suitability for service of the housing units. Tests applied by the BRD group included rail-car-coupling bumps at speeds up to 8 mph and monitoring responses to various wind forces, floor loadings, impacts to walls and floors, and earthquake-type tremors.

The division staff assisted the Public Building Service of the General Services Administration (GSA) by applying the performance concept to new government office buildings. Procurement by the GSA of Social Security Administration payment centers in San Francisco, Philadelphia, and Chicago followed evaluation by David B. Hattis and Thomas E. Ware.[246]

Whether designing by the performance approach or by traditional methods, the designer needed reliable estimates of the loads to be expected during the service life of any building. To update estimates of live loadings—weights of occupants, stored materials, and furnishings—and fire loadings in office buildings from values developed during the 1920s, James O. Bryson and Daniel Gross created new techniques for surveying and evaluating these parameters in 1968.[247] Based on their work, a national survey of loadings was conducted. The results formed the basis for national and international standards that are still in use for building design.[248]

[244] Richard N. Wright kindly furnished the information on which much of this section was based.

[245] "'Breakthrough' module here for testing by BRD," *NBS Standard*, Vol XVI, No. 3, March 1971, pp. 1, 16.

[246] David B. Hattis and Thomas E. Ware, "The Public Building Service performance specifications for office buildings," *NBS Report 10527*, January 1971.

[247] James Bryson and Daniel Gross, "Techniques for the survey and evaluation of live floor loads and fire loads in modern office buildings," *NBS BSS* **16**, 1968.

[248] Charles G. Culver and Jill S. Kushner, "A program for survey of fire loads and live loads in office buildings," *NBS Tech. Note 858*, 1975.

In 1967, NBS was asked to help improve efficiency and consistency in the writing and administration of building regulations. A group of concerned state governors collaborated with the Bureau Building Research Division (BRD) staff to create in 1969 the National Conference of States on Building Codes as a non-profit corporation. The Bureau provided the secretariat for the new organization under the guidance of Gene A. Rowland, former leader of the Wisconsin Building Code Section and in 1967 chief of the BRD Codes and Standards Section.[249]

Shortly after the new corporation was established, its member-delegates began to develop new, more uniform building regulations for states. These were later adopted by the Council of State Governments as model legislation.

Blest Be the Ties that Bind

A humble but essential service to the construction industry was provided by a Building Research Division team of Thomas W. Reichard, E. F. Carpenter, and Edgar V. Leyendecker when they completed an evaluation of the holding strength of inserts embedded in concrete. The information generated during the project was expected to materially aid the design of systems for the suspension of structural members or equipment from ceilings.

The team studied three different types of inserts, all intended to secure 3 inch bolts to a concrete ceiling. Commercially available concrete mixes were used with reinforcement in the test, with the inserts cast in place. In one test, a tensile load applied to each insert was increased until the insert was pulled from the concrete. Several other flexural and fatigue tests were also performed on the assemblies. The team found that the pull-out load could be approximated from material parameters, leading to the possibility for improved design recommendations.[250]

And the Walls Came Tumbling Down

Hollow walls, solid walls, brick walls, block walls, cavity walls. They all came tumbling down, in tests performed by Felix Y. Yokel, Robert G. Mathey, and Robert D. Dikkers. The object of the testing to destruction of more than 100 masonry walls was to establish their strength under axial, transverse, and "raking" (diagonal) loads in order to derive analytical procedures for the prediction of strength in service, and to aid in the design of masonry structures. Special assemblies for the application of directed, measured forces provided the basis for the experiments.

The project was successful in deriving predictive methods for the strength of masonry construction. It was expected that the results would lead to improved construction practices.[251]

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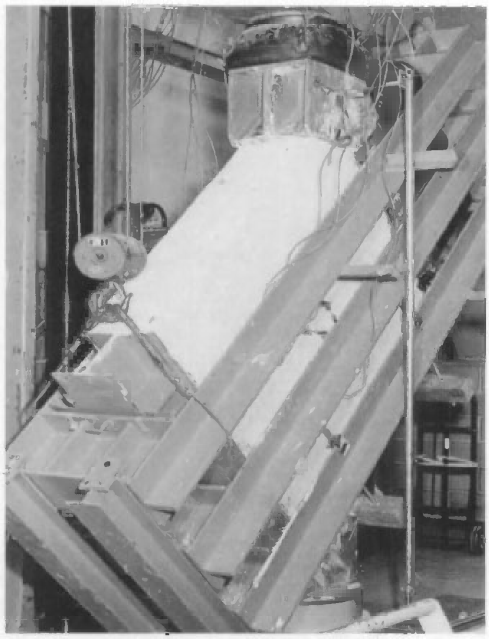
[249] Gene A. Rowland, "The increasing role of states in building codes and standards," *Proc. 26th Annual Conf. on Reinforced Plastics, Composites Division, Section 5B, February 10, 1971, Washington, DC,* pp. 1-3.

[250] T. W. Reichard, E. F. Carpenter, and E. V. Leyendecker, "Design loads for inserts embedded in concrete," *NBS Building Science Series* **42**, 28 pp., May 1972.

[251] "Transverse strength of masonry walls," *NBS Technical News Bulletin,* November 1970, p. 259.



A section of masonry wall, readied for strength testing under raking (diagonal) loads by personnel of the NBS Building Research Division.

The section of mansonry wall shown in the previous illustration, after testing to destruction under raking loads, exhibited the damage typically caused by such forces.

Applied Mathematics

100,000 "Handbooks"

We have seen in previous sections the fruits of the NBS applied mathematics effort mostly in terms of the program that gave statistical support to the Bureau's data-gathering scientists. A prime example of this support appeared in August 1969, when the *Handbook of Mathematical Functions* was reprinted for the seventh time. First published in 1964 under the careful editing of Irene A. Stegun, who finished the task begun years earlier in collaboration with the late Milton Abramowitz, the handbook was a best-seller.[252] In one of his final acts as retiring director of NBS, Allen V. Astin presented the 100,000th copy of the handbook to W. Reeves Tilley in recognition of his role in printing and publicizing the volume. An additional copy was presented to Lee A. DuBridge, Science Advisor to President Nixon.

Besides its data-analysis support of Bureau scientists, many other projects were undertaken by the Applied Mathematics Division staff. In the following, we present a small sampling of these projects.

NBS Deputy Director Lawrence M. Kushner (far right, above) served as a witness at the July 1, 1970 draft lottery.

[252] "Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables," Milton Abramowitz and Irene Stegun, editors, *NBS Applied Math. Series* **55**, June, 1964.

Making the Draft Fair

The Selective Service System (SSS) needed a dose of impartiality in 1970, so it paid a call on the NBS Applied Mathematics Division. The SSS called potential draftees for military service according to the date on which they turned 19 in a given year; the fateful birthdates were chosen in a random fashion. NBS was asked to provide 25 calendars with 25 random permutations of the numbers from 1 to 365 for use in selecting the order of drafting 1970's nineteen-year-olds for service in 1971.

Joan Rosenblatt, chief of the Statistical Engineering Laboratory (SEL), and James Filliben consulted with Churchill Eisenhart and Joseph Cameron, both former heads of the SEL, then selected the requested lists and checked them for randomness. The NBS work was examined by a panel of well-known statisticians outside the Bureau, then the lists were placed in 50 envelopes and carried to the SSS draft proceedings by NBS Deputy Director Lawrence Kushner and Rosenblatt.[253]

For this work and for other tasks performed in the course of her leadership of the SEL, Rosenblatt was selected to receive the 1971 Federal Woman's Award.[254]

Modeling the Flow of Truck Traffic

Judith Gilsinn of the Applied Mathematics Division and Richard Ku of the Technical Analysis Division collaborated to develop a mathematical model for truck traffic in the more congested parts of New York City. The work was performed on behalf of the Department of Housing and Urban Development. Utilizing traffic counts of four different types of trucks, the two researchers derived a model that answered questions about the usefulness of banning automobile traffic in certain areas and the principal reasons for congestion in the affected area.

More important than the immediate results of the study—that too few commercial establishments offered off-street loading and unloading—was the realization by HUD officials that mathematical modeling could substantially improve decisions reached by urban planners.[255]

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253 "NBS helps insure fairness of draft lottery," *NBS Standard,* Vol XV, no. 7, July 1970, p. 8.

254 "Dr. Joan Rosenblatt to receive 1971 Federal Woman's Award," *NBS Standard,* Vol XVI, No. 2, February 1971, pp. 1, 4.

255 "Computer roams downtown," *NBS Technical News Bulletin,* June 1971, pp. 139, 152.

Modeling Air Traffic

Robert Elbourn of the Center for Computer Sciences and Judith Gilsinn undertook a project with the objective of optimizing the assignment of transponder codes to aircraft as they entered an Air Traffic Control Center. Expecting a tripling of the number of aircraft operating under instrument flight rules by 1990, the Federal Aviation Administration asked NBS to help in the design of future identification systems.

Gilsinn and Elbourn considered a variety of options available to the Nation's nearly two dozen Control Centers, some of which would entail assigning a code number to each flight and others that would assign codes to each center. Evaluations were based upon comparisons of the efficiency of the models on the basis of actual air-control experience with nearly 28,000 flights connecting more than 1000 U.S. airports. Results of the modeling compelled FAA officials to consider trade-offs in the planning of future control systems.[256]

Research in Solid State Physics

In the following accounts, we highlight some of the varied projects undertaken at NBS in the area of solid state physics.

Crystal Structures at High Pressures

Study of crystal structures at high pressures fascinated certain members of the Crystallography Section of the Inorganic Materials Division. Charles E. Weir, Gasper J. Piermarini, and Stanley Block became especially adept at squeezing various materials between diamonds that had been shaped so as to exert pressures as high as 4 GPa (about 40,000 times atmospheric pressure) while still allowing an x-ray beam to pass through the sample.

In 1969 the trio published an account of their work, with details of construction of a high-pressure cell composed entirely of beryllium and diamond, both materials nearly transparent to x rays. The apparatus also incorporated a goniometer head and a modified Buergers-type camera. A flood of data followed, with structures of many high-pressure phases.[257]

The one problem most difficult to solve with the diamond-anvil cell was the determination of the actual pressure encountered by the squeezed sample. Only approximate methods, sometimes with uncertainties as high as 30 %, had been successful. John B. Wachtman, Jr., chief of the Inorganic Materials Division, brought forward a new idea—why not use as a standard the pressure shift in the luminescence spectrum of

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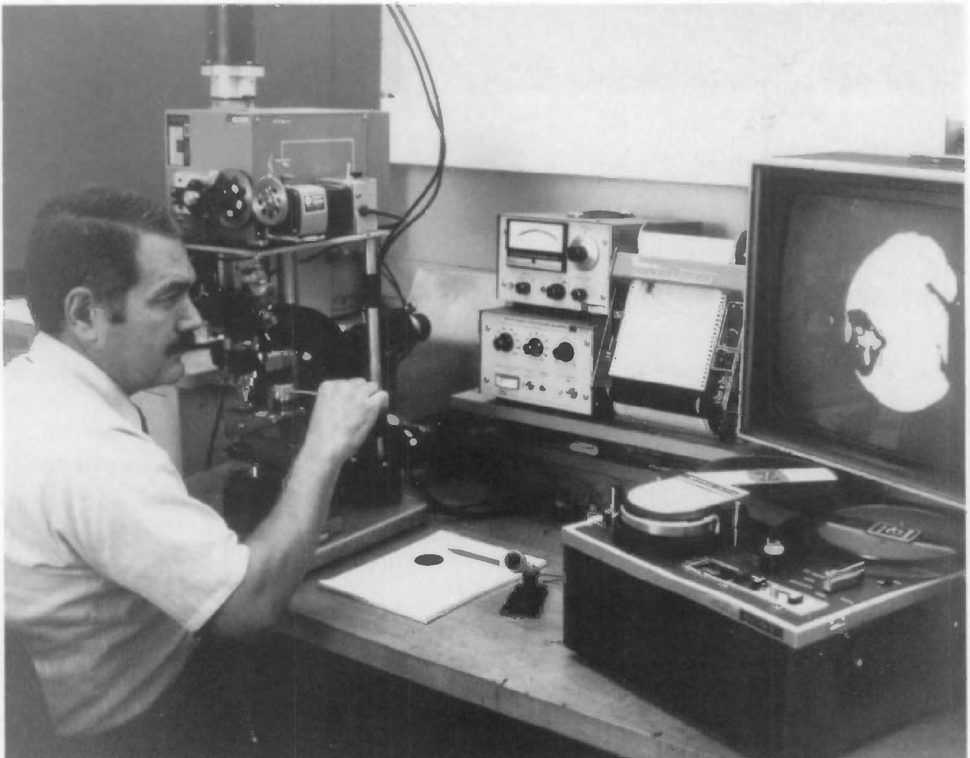
[256] R. D. Elbourn and Judith F. Gilsinn, "Simulation of air traffic control radar beacon code assignment plans," *NBS Technical Note 568,* March 1971.

[257] C. E. Weir, G. J. Piermarini, and S. Block, "Instrumentation for single-crystal x-ray diffraction at high pressures," *Rev. of Sci. Instrum.* **40**, 1133 (1969). See also C. E. Weir, G. J. Piermarini, and S. Block, "Crystallography of some high-pressure forms of C_6H_6, CS_2, CCl_4, and KNO_3," *J. Chem. Phys.* **50**, 2089-2093 (1969). See also G. J. Piermarini, A. D. Mighell, C. E. Weir, and S. Block, "Crystal structure of benzene II at 25 kilobars," *Science* **165**, 1250-1255 (1969). See also S. Block, C. E. Weir, and G. J. Piermarini, "Polymorphism in benzene, naphthalene, and anthracene at high pressure," *Science* **169**, 586 (1970).

ruby? Well, why not? thought Piermarini, Richard A. Forman, a young physicist in the neighboring Solid State Physics Section, and J. Dean Barnett, a colleague on sabbatical leave from Brigham Young University. So they tried Wachtman's suggestion.

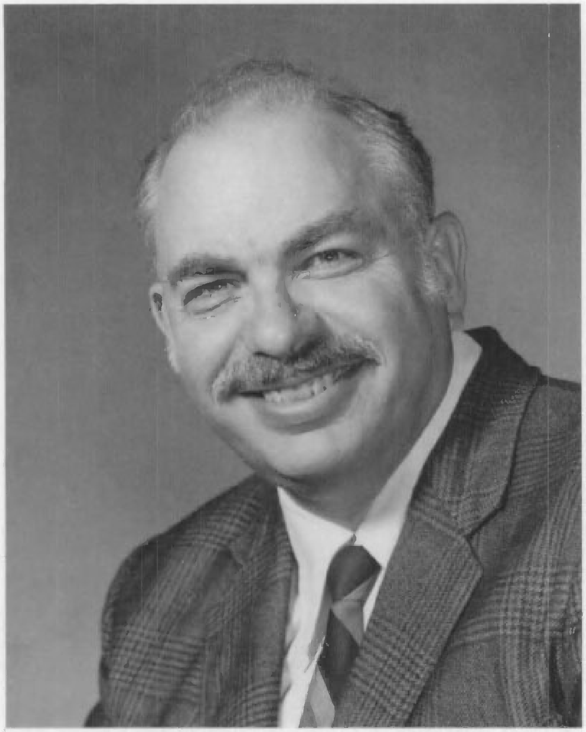
A small fragment of pink ruby containing less than 0.1 % Cr^{3+} ions, placed into the diamond anvil with the sample under study, provided an excellent pressure gage. Nearly linear with pressure up to 2000 MPa or so, the shifts in the R_1 and R_2 lines were easily observed.[258] The technique quickly became standard procedure for that type of experiment.

In 1974 Block and Piermarini were honored with the Department of Commerce Gold Medal for their work. The citation emphasized that the two had been able to make the new technology available to other laboratories where it had been applied to a wide variety of materials.



Using an activating rod, Gasper J. Piermarini raised the pressure in a diamond-anvil cell containing a zinc sulfide sample, which at about 7 GPa became metallic. The change to the metallic structure was recorded in photo sequence and displayed on the video monitor (right).

[258] Richard A. Forman, Gasper J. Piermarini, and J. Dean Barnett, "Pressure measurement made by the utilization of ruby sharp-line luminescence," *Science* **176**, 284 (1972).



Solid state physicist Stanley Block of the NBS Crystallography Section. With his colleagues Gasper Piermarini and Charles E. Weir, Block developed the diamond-anvil pressure cell.

High-Speed Measurements for High-Temperature Materials

Just as Lewis Branscomb was taking office as the Bureau's sixth director, several Bureau scientists were polishing the draft of a fairly long (27-page) paper describing a new technique in thermophysical-properties research on conductive refractory materials. The principles of the method were described by Charles W. Beckett and Ared Cezairliyan in Vol. I of the archival series, *Experimental Thermodynamics.*[259] In essence, they used very rapid measurements to obtain heat-capacity and radiative-property data at temperatures so high as to be out of reach by normal techniques.

Acknowledging support from the U.S. Air Force Office of Scientific Research program in high-temperature materials, Cezairliyan, Malcolm S. Morse, Horace A. Berman, and Beckett soon presented the first results obtained by the use of the new technique.[260] The scientists pointed out that they could obtain thermodynamic data on certain samples without the lengthy exposure to high temperatures required by earlier techniques. That long exposure frequently led to unwanted chemical reactions,

[259] C. W. Beckett and A. Cezairliyan, "High-Speed Thermodynamic Measurements and Related Techniques," in *Experimental Thermodynamics*, Vol I Calorimetry of Non-Reacting Systems, J. P. McCullough and D. W. Scott, Editors, Butterworths, London, 1968, p. 551.

[260] A. Cezairliyan, M. S. Morse, H. A. Berman, and C. W. Beckett, "High-Speed (Subsecond) Measurement of Heat Capacity, Electrical Resistivity, and Thermal Radiation Properties of Molybdenum in the Range 1900 to 2800 K," *J. Res. NBS* **74A**, No. 1, 1970, pp. 65-92.

Physicist Ared Cezairliyan operated this apparatus to obtain high-temperature thermodynamic data in sub-second time intervals.

excessive heat transfer, evaporation, diffusion, or loss of mechanical strength. Various workers throughout the world had attempted to obtain such information, but they had lacked the experimental resources needed to obtain useful and accurate values.

In the first detailed publication on the new technique, the group reported studies of the element molybdenum, a transition metal with a high melting temperature (~2610 °C). The new technique required that a subsecond pulse of resistive heating be applied to the sample, which was shaped in the form of a tube 10 cm long, 0.6 cm outside diameter, and 0.05 cm wall thickness. A tiny rectangular hole (0.1 cm × 0.05 cm) in the sample wall permitted the observation—by a newly-acquired, high-speed photoelectric radiometer—of thermal radiation from inside the sample. Potential probes in the form of Mo knife-edges defined the limits of an isothermal section of the sample and were used to obtain time-dependent voltage data. Thermocouple thermometers connected to the ends of the sample yielded pre-pulse sample temperatures. The sample environment could be regulated to approximate a vacuum or a selected gaseous environment.

A 28 V heavy-duty battery bank supplied the pulse power to the sample through a variable series resistor and a standard 0.001 Ω current-measuring resistor. From the standard resistor the current through the sample could be determined; combining this information with the time-dependent voltage data allowed evaluation of the time-dependent resistivity of the sample.

Cezairliyan and his co-workers obtained results on the heat capacity of molybdenum that agreed within 1 % to 8 % with values obtained by other experiments over the range 2000 K to 2800 K. Electrical-resistivity results agreed somewhat better, within 2 % over the same range of temperature. The largest source of error in the sample thermometry was caused by non-uniformity of the sample temperature—from approximately 3 K at 2000 K to about 4 K at 2800 K. At the higher temperatures, the uncertainty of calibration of the standard lamp used as a reference source contributed significantly to the overall uncertainty of the measurement.

In assessing the quality of their work, the authors pondered the question of internal thermodynamic equilibrium in the sample during such rapid experiments: they concluded that the electron-phonon interaction rate was sufficiently fast that no disequilibrium need be expected from this source. The relaxation rate for lattice vacancies was slower; along with changes in impurity content and grain growth, this source of variation in heat capacity was thought to account for the 1.3 % to 2.2 % variation in heat-capacity determinations found among the several series of measurements in the experiment. The authors were encouraged by the level of agreement of their results with those expected for molybdenum in the temperature range studied. Although they would spend some years in evaluating and reducing the uncertainties of the new method, they expected it to produce useful high-temperature results that could be obtained in no other way. Subsequent experience would prove them correct.

Getting in Touch with Semiconductors

Defective bonding of wire leads to metallized semiconductor surfaces caused many failures in the early days of microcircuit manufacture. An effort to pinpoint causes of the defects occupied scientists from the Electronic Technology Division for several years. Early in the project, George G. Harman and Herbert K. Kessler adapted various types of capacitive and magnetic pickup devices to detect motion of the bonded elements.[261]

William R. Hosler developed an improved method of preparing low-resistance contacts on semiconductors during this period, providing assistance to researchers using devices such as thermistors, diodes, and photodetectors. In making certain measurements—for example magnetoresistance, piezoresistance, or Hall effect—high-resistance contacts prevented the acquisition of accurate data; not infrequently, such contacts failed during testing.

For materials such as potassium tantalate, strontium or barium titanate, and titanium dioxide, the secret, according to Hosler, was the use of a special flux, TiH_2. Hosler pressed the solid flux and the metal button used to make the contact into a slight depression on the surface of the sample and heated the assembly in a furnace with an inert atmosphere. Whereas conventional methods might yield a contact resistance of several tenths of an ohm at 4.2 K, Hosler's technique provided contacts with resistances in the milliohm range.[262]

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[261] G. G. Harman and H. K. Kessler, "Application of capacitor microphones and magnetic pickups to the tuning and trouble shooting of microelectronic ultrasonic bonding equipment," *NBS Tech. Note 573,* April 1971.

[262] W. R. Hosler, "Low resistance contacts on semiconducting oxides," *Solid-State Electron.* **13**, 517-519 (1970).

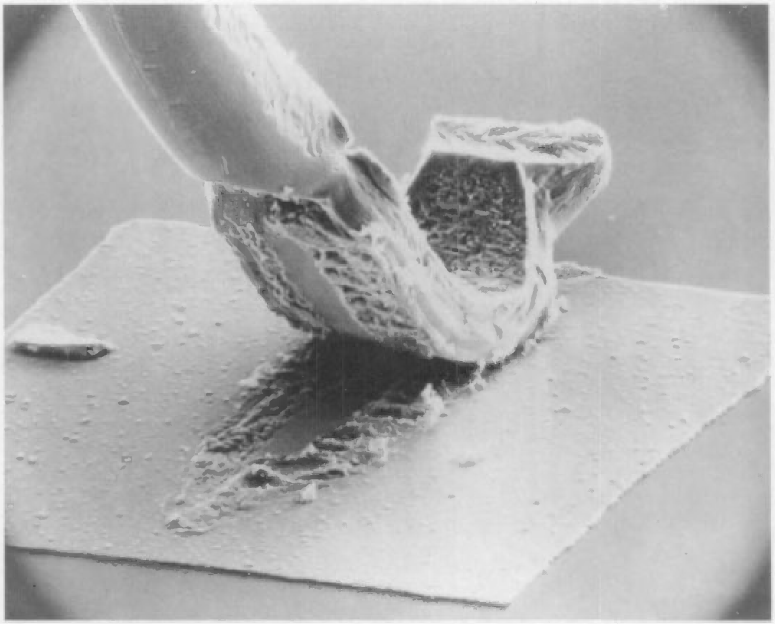
In research to determine the cause of failures in microelectronic wire bonds, Herbert Kessler positioned a magnetic pickup beside the end of an ultrasonic tool used to bond aluminum wire leads to metallized pads on semiconductor wafers. Using an oscilloscopic display of the pickup signal, he could adjust the transducer driver to the desired frequency and amplitude at the tool tip.

Tuning a Radiation Detector

Lithium-compensated germanium gamma ray detectors had been in use for some time when a "glitch" developed; certain of the devices were found to be defective for no apparent reason. Because of the usefulness of the detectors in measuring the energy of nuclear radiation, any problem was considered serious by the Atomic Energy Commission. The AEC contacted Alvin H. Sher of the Electronic Technology Division to see what could be done.

At NBS, William Croll and Howard Dyson were able to duplicate the vacuum deposition of lithium on the surface of p-type germanium and heat-diffuse the lithium to create the detector material. William Keery and Sher determined the energy-resolving characteristics of the completed detectors, while J. Robert Thurber measured the oxygen content in the germanium base material. The Bureau work was of great benefit in reducing the number of defective detectors. The results of the NBS work appeared in new preparation standards issued by the American Society for Testing and Materials.[263]

[263] "Evaluating nuclear radiation detectors," *NBS Tech. News Bull.*, April 1972, pp. 85-86.



The scanning electron microscope was used in NBS semiconductor technology research to evaluate the bond between wire leads and semiconductor surfaces. This scan showed an area of good adhesion surrounding an unbonded area.

Applications of Paramagnetism

During 1972, Ralph P. Hudson, Chief of the Heat Division, completed a monograph on the use of paramagnetic materials in low-temperature physics research. Using paramagnetic salts with the technique of adiabatic demagnetization, scientists could cool samples of many types to temperatures as low as 0.001 K. Using carefully prepared paramagnetic thermometers, they could measure temperatures in the range 0.001 K to perhaps 90 K.

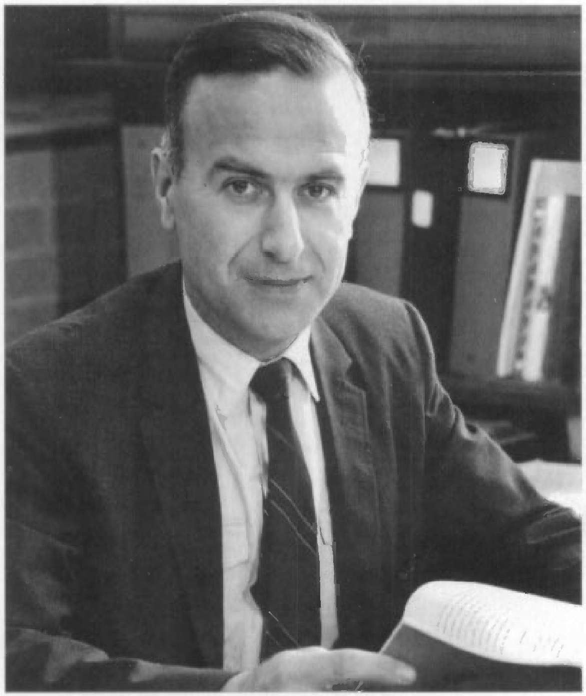
One of the most notable uses of paramagnetic materials at NBS, the demonstration in 1956 of parity non-conservation in weak nuclear interactions, involved both these methods. Along with Ernest Ambler, Raymond W. Hayward, and Dale D. Hoppes, Hudson had received the Department of Commerce Gold Medal award for that work.[264]

After the ^{3}He-^{4}He dilution refrigerator (see Ch. 1) was introduced in the late 1960s, paramagnetic thermometry was used for many years to provide reliable system temperatures.

In his monograph, Hudson discussed the thermodynamic principles involved in paramagnetic cooling and in paramagnetic thermometry. He also reviewed current experimental techniques, similar to those mentioned earlier in this chapter.[265]

[264] See, for example, Elio Passaglia, *AUI*, pp. 207-213.

[265] R. P. Hudson, "Principles and application of magnetic cooling," *Series in Low Temperature Physics* **2**, 1-230 (Amsterdam: North-Holland Publishing Co., 1972).



Ralph P. Hudson was chief of the NBS Heat Division from 1960 to 1978. He maintained an active interest in the fields of low-temperature thermometry and magnetism throughout that time.

New Drive for Soft X-Ray Spectrometers

In order to improve the constancy of resolution of the soft x-ray spectrometer during changes in wavelength, John R. Cuthill developed a new detector drive for the instrument. There were many applications for soft x-ray spectrometry at that time—spectrographic analysis for light elements and evaluating the density of electronic states in the valence bands of conductors, to name two. Often home-made, the instruments were consistently under improvement.

Cuthill's modification involved the use of a lead screw that moved the detector along a curved track. In his arrangement, it also aimed the detector at the grating, holding the effective slit width constant throughout the wavelength range. The device thus controlled the spectrometer resolution at a fixed value. An added benefit was an improvement in rigidity of the spectrometer.[266]

Prize-Winning Research in Solid State Science

Recognition came to several other Bureau staff members in recognition of the high quality of their work in the solid state sciences during Branscomb's tenure as Director:

[266] J. R. Cuthill, "A soft x-ray spectrometer with improved drive," *Rev. Sci. Instrum.* **41**, pp. 422-423 (1970).

A digital printout of an emission spectrum from a soft-x-ray spectrometer was examined by its designer, John Cuthill. All optical and some mechanical components of the spectrometer were housed in the large cylinder (center). Data were recorded on a stripchart (left), on paper (foreground), and on magnetic tape (right) for input into a computer.

- Alan D. Franklin received the 1970 Department of Commerce Gold Medal for his work on point defects in solids.[267] During this period, Franklin calculated the energies required to form point defects in ionic crystals, using a general formulation of the Born model; he also calculated specific values for CaF_2. He found that the calculations of the energy to form anion Frenkel pairs (2.7 eV per pair), to form cation Frenkel pairs (7.5 eV per pair), and to form Schottky trios (5.1 eV per trio), agreed reasonably well with recent experimental results, justifying the use of the Born model.[268]
- Herbert S. Bennett was named the Outstanding Young Scientist of 1970 by the Maryland Academy of Sciences, for:

  Extensive theoretical work on ferromagnetism near the Curie temperature; analysis of temperatures and stresses induced in laser glasses in high radiation fields; and especially for his development of the calculation of F centers in oxides.[269]

[267] "22nd annual Commerce honor awards presented," *NBS Standard,* Vol XV, No. 11, November 1970, pp. 1, 13.

[268] A. D. Franklin, "Born model calculation of defect energies in CaF_2," *J. Phys. Chem. Solids* **29**, 823-841 (1968).

[269] "Dr. Bennett honored by Md. Academy of Sciences," *NBS Standard,* Vol XVI, No. 2, February, 1971, pp. 6, 8.

During the same period, Bennett continued two series of theoretical investigations. One, attempting to elucidate the nature of F centers in ionic crystals, considered models that invoked a self-consistent treatment of the movement of the nearest neighbors to the F center. A second contribution treated the propagation of sound waves in ferromagnetic and antiferromagnetic insulators. In both cases, Bennett evaluated his efforts by comparing calculated results with those obtained experimentally.[270]

Bennett and Franklin, both members of the Inorganic Materials Division, shared the editorial tasks involved in summarizing the Bureau program of research, accomplished with the sponsorship of the Advanced Research Projects Agency, on materials for use in high-temperature work and in lasers.[271]

- Lawrence H. Bennett, a physicist in the Metallurgy Division (no relation to Herbert), was honored with the award of the Department of Commerce Gold Medal in 1971 for his work in metal physics.[272] Bennett was a prolific experimenter, the author or co-author of a dozen papers from 1966 to 1970. Either alone or with one or more of his colleagues Lyden J. Swartzendruber, Russell W. Mebs, Gesina C. Carter, Irwin D. Weisman, and J. C. Swartz of NBS and the team of Richard E. Watson and A. J. Freeman—both employed by Brookhaven National Laboratory—Bennett investigated a variety of solid state physics topics. These included nuclear resonance, ferromagnetic materials, the Mössbauer effect, the Knight shift, and magnetic clusters. Bennett also wrote a review of nuclear magnetism.[273]

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[270] H. S. Bennett, "F center in ionic crystals II. Polarizable-ion models," *Phys. Rev.* **184**, No. 3, 918-935 (1969). H. S. Bennett, "Frequency shifts of acoustic phonons in Heisenberg Paramagnets III," *Phys. Rev.* **185**, No. 2. 801-804 (1970).

[271] "ARPA-NBS program of research on high temperature materials and laser materials, January 1-June 30, 1969," *NBS Technical Note 514*, A. D. Franklin and H. S. Bennett, editors, January 1970, 98 pp. See also "ARPA-NBS program of research on high temperature materials and laser materials, July 1 -December 31, 1969," *NBS Technical Note 531*, A. D. Franklin and H. S. Bennett, editors, June 1970, 75 pp.

[272] See p. 1, *NBS Standard* Vol XVI, No. 10, November 1971.

[273] L. H. Bennett, "Influence of an external magnetic field on nuclear resonance in ferromagnetic materials," *J. Appl. Phys.* **37**, No. 3, 1242-1243 (1966). See also L. H. Bennett and L. J. Swartzendruber. "Ferromagnetic iron alloys lacking a hyperfine field at the iron site," *Phys. Lett.* **24A**, No. 7, 359-360 (1967). See also R. E. Watson, L. H. Bennett, and A. J. Freeman, "Origin of solvent Knight shift in alloys," *Phys. Rev. Lett.* **20**, No. 13, 653-656 (1968). See also L. H. Bennett, L. J. Swartzendruber, and R. E. Watson, "Magnetic clusters associated with isolated Fe atoms in paramagnetic Cu-Ni alloys," *Phys. Rev. Lett.* **23**, No. 20, 1171-1174 (1969). See also Swartzendruber and Bennett, "Clustering, cold work, and the Mössbauer effect doublet structure in Cu-Ni-Fe alloys," *Phys. Lett.* **31A**, No. 10, 581-582 (1970). See also L. H. Bennett, "Nuclear Magnetism," chapter 14 in *Magnetism and Magnetic Materials, 1968 Digest*, H. Chang and T. R. McGuire, editors (New York: Academic Press, 1968) pp. 201-221.

- Judson C. French was presented the 1971 NBS Edward B. Rosa award for:

> Leadership in the standardization of the methods of measurement used to specify the properties of electron devices, the materials from which they are made, and the processes used in their fabrication.[274]

The scientific work done by French contributed substantially to an understanding of the electronic phenomenon of "second breakdown" and to the development of a new basis for specifying safe operating conditions for transistors. French was responsible for a major improvement in the use of four-probe resistivity measurements on germanium and silicon samples.

Center for Radiation Research

Projects undertaken by the staff of the Center for Radiation Research included theoretical studies, dosage standards, and hot-laboratory cleanup methods, described in the following accounts. Already noted in this chapter was the achievement of criticality in the NBS nuclear reactor.

Handling Hot Accelerators

When a particle-accelerator run was finished, the investigators usually went away happy. The accelerator operators, however, faced the problem of replacing samples and preparing the machine for further use. Often, this process was complicated by radioactivity induced in the materials from which the accelerator itself was made. James M. Wyckoff of the Linac Radiation Division provided the Health Physics group with information on the types and intensities of radiation to be expected as a result of induced radioactivity.

Wyckoff obtained data on the spallation products to be expected from the use of several materials commonly used to build accelerators, including aluminum, iron, nickel, and copper.[275] He calculated the energy emitted as photons over the time range of 1 hour to 4 years after irradiation took place, allowing operators to cope with "hot" accelerators, and designers to minimize especially unfavorable materials in accelerator construction.

Measuring Radioactivity Doses

During this period, physicists in the Applied Radiation Division developed a radiation-measurement procedure that used films and gels to measure dosages of radiation. Radiation monitors were a necessity for those involved in industrial radiation processing of foods, medical supplies, and other materials. William L. McLaughlin, Eckhart K. Hussmann—a guest worker from the Max Planck Institute in Frankfurt,

[274] "Stratton and Rosa awards presented," *NBS Standard,* Vol XVI, No. 6, June 1971, pp. 1, 11, 12.

[275] J. M. Wyckoff, "Photon energy emission from spallation products produced by 3-13 GeV electrons," *Health Phys.* **18**, 693-704 (1970).

Germany—H. H. Eisenlohr of the International Atomic Energy Agency in Vienna, and Lyman Chalkley of LaJolla, California prepared solutions that were initially colorless but assumed a stable blue-violet color when irradiated with doses from 1 krad to 100 krad. The color change provided an easy-to-read visual indication, and more precise dosage information could be obtained by measuring the optical density of the dosimeter.[276]

Hussmann and McLaughlin provided a dosimetric method for a more technical purpose as well. They developed a holographic interferometer technique that relied upon the change of refractive index of a transparent liquid. The spatial distribution of absorbed dose could be determined by observation of the liquid, taking advantage of the fact that small changes in local temperature, arising from the irradiation, were accompanied by changes in refractive index. They found the method to be especially useful for high-intensity pulsed radiation.[277]

In the area of neutron dosimetry, Valentine Spiegel, Jr. and his associates studied the geometry of neutron penetration in a variety of substances, including liquid baths. These studies often involved foils which became radioactive upon exposure to neutrons. The degree of activation allowed evaluation of the dosage at various positions from sources configured in specific geometric forms. With his colleague William M. Murphey, Spiegel prepared a computer code for the calculation of thermal neutron self-absorption for cylindrical and spherical sources, using dosage measurements in a manganous sulfate bath to confirm the results.[278]

Verifying a Nuclear Theory

Robert B. Schwartz, Roald A. Schrack, and Henry T. Heaton of the Bureau's Nuclear Radiation Division puzzled over a scientific bulletin sent from a laboratory in Hungary. Two Hungarian scientists had measured the energy dependence of the scattering cross-section for neutrons and protons.[279] They found regular deviations of about 5 % from smoothness in the cross-section curve that called into question the accepted theory of n-p scattering, which dictated a smooth, monotonic decrease in the cross-section with energy. The three NBS physicists realized that they could quickly measure the cross-sections to verify or refute the new data.

Immediately the Bureau team prepared a polyethylene target for irradiation by the NBS electron linear accelerator. The hydrogen atoms contained in the polyethylene furnished target protons, and the linac electron beam was directed to another target to produce neutrons of varying energy. Plotting the resulting data showing cross section

[276] W. L. McLaughlin, E. K. Hussmann, H. H. Eisenlohr and L. Chalkley, "A chemical dosimeter for monitoring gamma-radiation doses of 1-100 krad," *Intern. J. Appl. Radiation Isotopes* **22**, 135-140 (1971).

[277] E. K. Hussmann and W. L. McLaughlin, "Dose-distribution measurement of high-intensity pulsed radiation by means of holographic interferometry," *Radiation Res.* **47**, No. 1, 1-14 (1971).

[278] V. Spiegel, Jr. and W. M. Murphey, "Calculation of thermal neutron adsorption in cylindrical and spherical neutron sources," *Metrologia* **7**, No. 1, pp. 34-38 (1971).

[279] Gy. Hrehuss and T. Czibók, "Oscillations in the energy dependence of the n-p scattering cross section," *Phys. Lett.* **28B**, No. 9, 585-587 (1969).

Valentine Spiegel, Jr. and his assistant Linda Cline determined neutron penetration depths in a water bath, using foil detectors positioned at precise distances from the source. After neutron activation, the foils were placed in a radioactivity counter to measure neutron fluence.

vs energy, Schwartz, Schrack, and Heaton found a curve that was smooth within 0.5 %, verifying the original theoretical prediction.[280] Similar experiments elsewhere corroborated the NBS work.

Recognition for CRR Scientists

Martin J. Berger, Chief of the Radiation Theory Section, CRR, was awarded the Department of Commerce Gold Medal for his work in radiation-transport theory and its application to radiation-engineering problems. An example of that type of research was produced by Berger and Stephen M. Seltzer, who used a Monte Carlo technique to calculate the penetration of fast electrons through water. They were able to account for multiple atom-electron scattering (both elastic and inelastic) as well as the influence of bremsstrahlung effects, producing information on the spatial distribution of energy deposition, charge deposition, and electron flux.[281] A similar set of calculations, performed for the case of aluminum targets, aided the cause of protection against space radiation.

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[280] R. B. Schwartz, R. A. Schrack, and H. T. Heaton, "A search for structure in the n-p scattering cross section," *Phys. Lett.* **30B**, No. 1, 36-38 (1969).

[281] M. J. Berger and S. M. Seltzer, "Calculation of energy and charge deposition and of the electron flux in a water medium bombarded with 20-eV electrons," *Ann. N. Y. Acad. Sci.* **161**, Art 1, 8-23 (1969).

Berger also utilized point kernel theory to evaluate the effects of beta irradiation dosimetry for medical purposes.[282]

Everett G. Fuller and Evans V. Hayward shared the Department of Commerce Gold Medal in 1971 for:

> Pioneering work in experimental photonuclear physics that provided the scientific basis for various practical applications of high energy x- and gamma rays.

An example of Hayward's work was a monograph on photonuclear reactions in which she reviewed progress in the energy range from 10 MeV to 30 MeV. Hayward compared the predictions of several theories against existing experimental data, noting where discrepancies provided incentives for further work.[283] Similarly, Fuller prepared a discourse on photoneutron reactions.[284]

Progress in Polymer Physics

Lauritzen and Hoffman Share High Polymer Physics Prize

The American Physical Society awarded its High Polymer Physics Prize jointly to two NBS scientists in March 1970. The prize, sponsored by the Ford Motor Company, was given to John I. Lauritzen, Jr. and John D. Hoffman for:

> Their theoretical contributions to the understanding of molecular motions in solids, and, in particular, for their kinetic theory of polymer crystallization.[285]

Lauritzen held the title of Institute Scientist in the Institute for Materials Research at that time; Hoffman was Director of the institute. Both had served NBS since the mid-1950s. An example of recent work by the pair, accomplished in collaboration with Elio Passaglia, Gaylon S. Ross, Lois J. Frolen, and James J. Weeks, was a detailed study of theories treating the kinetics of polymer crystallization.[286] In that work, the scientists reviewed nucleation theories for chain-folded polymers; special attention was given to prior work on fluctuations by Passaglia and Lauritzen. The study contributed new understanding to the developing theory of large polymers.

Receiving awards for their scientific work was not unusual for the two scientists. Hoffman received the Department of Commerce Gold Medal in 1965 and the NBS Samuel Wesley Stratton award in 1967 for his polymer investigations, and Lauritzen shared the Stratton award in 1971 with Passaglia and Edmund DiMarzio.

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[282] M. J. Berger, "Beta-ray dosimetry calculations with the use of point kernels," *Atomic Energy Commission Report* **CONF-691212**, June 1970, pp. 63-86.

[283] E. Hayward, "Photonuclear Reactions," *NBS Monograph 118* August 1970, 46 pp.

[284] E. G. Fuller, "Photoneutron reactions," pp. 359-375 in *Nuclear Structure Study with Neutrons* (Amsterdam: North-Holland Publ. Co, 1966).

[285] "Dr. Hoffman and Dr. Lauritzen share APS physics prize," *NBS Standard,* Vol XVI, No. 5, May 1971, p. 1.

[286] J. D. Hoffman, J. I. Lauritzen, Jr., E. Passaglia, G. S. Ross, L. J. Frolen, and J. J. Weeks, "Kinetics of polymer crystallization from solution and the melt," *Kolloid-Z. Polymere* **231**, Nos. 1 & 2, 564-592 (1969).

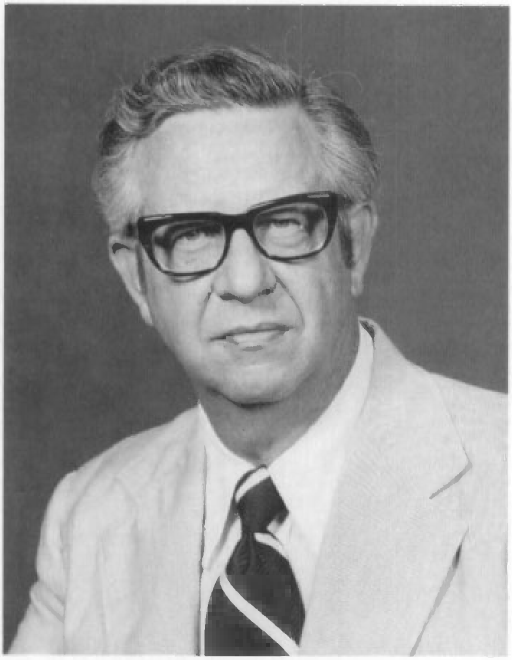
John I. Lauritzen, Jr. joined the NBS Dielectrics Section in 1956 and worked there until his death in 1976. His special interest was the theory of polymer crystallization.

Biting into Dental Problems

The long-standing collaboration between NBS and the world of dentistry produced many advances for the public. George Dickson, Assistant Chief of the Dental Research Section of the Polymers Division, was recognized for his contributions to these advances in March 1972, when the International Association for Dental Research presented him with the Wilmer Souder Award, the highest honor in the field of dental materials.

It is worthwhile to recall the contributions made by Wilmer S. Souder to the Nation's dental health. Souder, a Bureau physicist, responded to a request made during World War I by the Surgeon General that the Bureau of Standards investigate the science underlying dentistry to improve the woeful state of soldiers' teeth. Souder was appalled at the lack of scientific information at the base of dental practice at the time. His review of the situation prompted a commercial laboratory to initiate support of a program of dental studies at the Bureau. Because his administrative efforts were matched by outstanding scientific work on behalf of the Nation's dentists, Souder became known as "The Father of Dental Materials Research."[287]

[287] G. C. Paffenbarger and N. W. Rupp, "History of the International Association for Dental Research Wilmer Souder Award in Dental Materials, with a short biography of Wilmer Souder," *Dental Materials* 2, pp. 49-52 (1986).



John D. Hoffman retained an active interest in polymer theory even as he served as director of the NBS Institute for Materials Research from 1967-1978 and the director of the National Measurement Laboratory from 1978-1982.

Dickson, a Bureau staff member for two decades, was one of a large group of productive researchers. Work during that period included studies of the properties of dental amalgams and of instrumentation used in dental research.[288]

George C. Paffenbarger and Guest Worker J.B. Woelfel provided some basic data to benefit wearers of dentures as a result of a long-term study. Two sets of upper and lower dentures, one made of vulcanite and one of epoxy, were evaluated periodically for serviceability and shrinkage over a 7-year test in which the dentures were worn on a continuing basis. Paffenbarger and Woelfel reported finding deterioration of the dentures, and they described tests that identified the probable causes.[289]

Paffenbarger, former director of the American Dental Association research unit at NBS, was awarded the Miller International Prize at the 15th World Dental Congress in Mexico City during October 1972, "for the most eminent services to science."[290]

[288] P. L. Oglesby, G. Dickson, M. L. Rodriguez, R. M. Davenport, and W. T. Sweeney, "Viscoelastic behavior of dental amalgams," *J. Res. NBS* **72C**, No. 3, 203-213 (1968). See also G. Dickson, P. Oglesby, and R. Davenport, "The steady-state creep behavior of dental amalgams," *J. Res. NBS* **72C**, No. 3, 215-218 (1968). See also J. D. Eick, H. J. Caul, T. Hegdahl, and G. Dickson, "Chemical composition of dental gold casting alloy and dental wrought gold alloys," *J. Dental Res.* **48**, No. 6, 1284-1289 (1969). See also T. V. Gardner, Jr. , G. Dickson, and J. W. Kumpala, "Application of diffraction gratings to measurement of strain of dental mterials," *J. Dental Res.* **47**, No. 6, Part 2, 1104-1110 (1968).

[289] J. B. Woelfel and G. C. Paffenbarger, "Expanding and shrinking 7-year-old dentures: report of cases," *J. Am. Dental Assoc.* **81**, No. 6, 1342-1348 (1970).

[290] See *NBS Standard,* March 1973, p. 3.

Elio Passaglia had a diverse career at NBS, at various times serving as chief of the Polymer Physics Section and the Metallurgy Division, Deputy Director of the Center for Materials Research, and chief of the Office of Flammable Fabrics. He also wrote a history of NBS covering the period 1951-1969.

Paffenbarger, the first professional dentist to engage in research at NBS, retired in 1968 after 38 years as an ADA research associate. In April 1985, NBS established the Paffenbarger Research Center within the Polymers Division in honor of his contributions to the field of dentistry.

Optical Physics Research

Optical physics research covered a wide range of activities indeed. Many projects that could have been included in this section can be found elsewhere in this chapter. Here we present just a sampling of such projects.

Far Ultraviolet Spectrum of Lithium

A difficult experiment was successfully completed during 1970 through the cooperation of a large group of people, both from NBS and elsewhere. The experiment involved the observation and analysis of the spectrum of atomic lithium in the range 22 nm to 17 nm (56 eV to 70 eV). Lithium is extremely reactive; this property provided a non-trivial complication in any such experiment. In addition, the spectral range of the study, chosen for its significance to astronomical work, was far from the easiest to observe. Finally, interpretation of the results of the experiment presented its own challenge.

David L. Ederer, Thomas B. Lucatorto, and Robert P. Madden of the Optical Physics Division (OPD) built an experimental chamber modeled after a heat-pipe oven developed by C. R. Vidal and J. Cooper of the Radio Standards Physics Division in

Edmund A. DiMarzio, a theoretical physicist, joined the NBS Polymer Physics Section in 1963. He shared the High Polymer Physics prize of the American Physical Society in 1967.

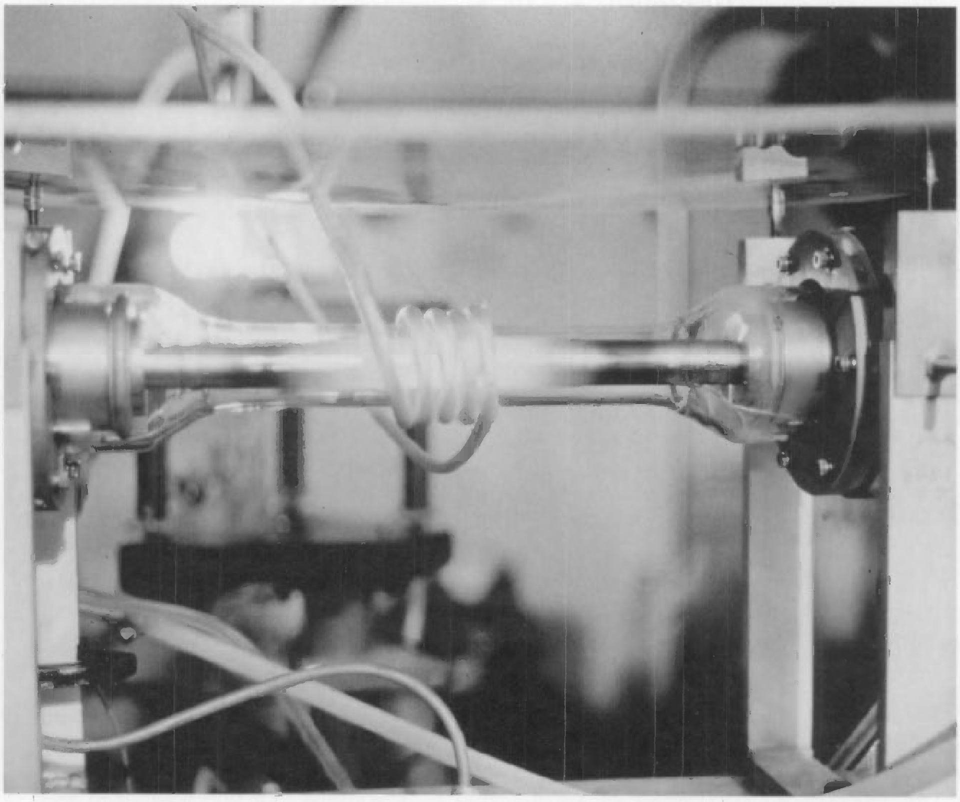
Boulder.[291] In the oven, lithium vapor was isolated within the center portion of a stainless-steel cylinder contained in a quartz vacuum tube. The technique utilized an external rf coil and an internal stainless-steel wick to regulate the temperature of the lithium vapor within 1 °C of 725 °C. The NBS 180 MeV electron synchrotron provided high-intensity radiation, which was directed through thin aluminum windows at the ends of the heat pipe and collected in a grazing-incidence spectrograph.[292] The hot-lithium line spectra were analyzed in terms of the states of excited lithium by Andrew W. Weiss and John W. Cooper of the OPD and colleagues M. J. Conneely, Kenneth Smith, and Stephan Ormonde from the University of Nebraska and Quantum Systems, Inc.[293]

Using the results obtained in this experiment, the investigators were the first to elucidate the autoionizing states of lithium, which were thought to involve K-shell and/or valence electron excitation. Astronomers utilized the new results to refine estimates of the concentration of lithium in the solar atmosphere.

[291] C. R. Vidal and J. Cooper, "Heat pipe oven: a new, well-defined metal vapor device for spectroscopic measurements," *J. Appl. Phys.* **40**, No. 8, 3370-3374 (1969).

[292] D. L. Ederer, T. Lucatorto, and R. P. Madden, "Autoionization spectra of lithium," *Phys. Rev. Lett.* **25**, No. 22, 1537-1540 (1970).

[293] J. W. Cooper, M. J. Conneely, Kenneth Smith, and Stephan Ormonde, "Resonant structure of lithium between the 2^3S and 2^1P thresholds," *Phys. Rev. Lett.* **25**, No. 22, 1540-1543 (1970).



The absorption spectrum of lithium was investigated from 56 eV to 70 eV using the NBS synchrotron and the lithium heat pipe oven shown here. Lithium was vaporized in the stainless steel, horizontal pipe oven (center), which was enclosed within a quartz vacuum tube and heated by an exterior rf coil. Viewing windows were enclosed within the solid cooling sections at each end of the quartz tube.

Transition Probabilities in the Vacuum Ultraviolet

Hard on the heels of the lithium work described above came the first NBS measurements of transition probabilities in the vacuum-ultraviolet spectral region. William R. Ott of the Optical Physics Division used a wall-stabilized arc, operating in a mixture of argon and oxygen, and a new 3-meter high-resolution scanning monochromator to measure the transition probabilities for neutral oxygen.[294] Ott chose

[294] W. R. Ott, "Measurement of transition probabilities for O I in the vacuum ultraviolet," *Phys. Rev.* **A4**, No. 1, pp. 245-251 (1971).

oxygen for the first measurements in an attempt to resolve outstanding discrepancies found in other experiments, and because of the importance of the transition probabilities in determining stellar oxygen densities.

New Test for Quality Optics

Many procedures used in optical physics depended on the quality of optical components. In 1970, James B. Saunders developed a new method to test the quality of optical parts; it was sufficiently simple to be used in the workshop. The technique used a wavefront-shearing interferometer—basically a composite prism of cubical shape—plus a light source. The prism could be prepared so as to yield various amounts of shear; Saunders recommended the range 3 milliradians to 12 milliradians. In use, the operator viewed an interference pattern produced by the interferometer as light was reflected from the optical component under test. The pattern could be interpreted either visually or quantitatively to evaluate the quality of the component, typically a lens or a mirror.[295]

Optical Properties of Laser Materials

Heat and pressure both caused changes in the index of refraction of the materials from which glass and crystal lasers were constructed. Uneven or unsteady application of heat or pressure caused the index of refraction to vary with position or time. In turn, the changing index of refraction caused distortion of the wavefront of the light emitted by the laser. Roy M. Waxler, Given W. Cleek, Edward Farabaugh, and Albert Feldman found that the piezo-optic and thermo-optic properties of laser materials including ruby and five different compositions of neodymium-doped glass were only poorly known, so they set about to measure them.

Measurements of the thermo-optic constants of the materials involved use of a Fizeau interferometer to observe the change of refractive index with temperature over the range 0 °C to 300 °C for the neodymium glasses and 0 °C to 600 °C for the ruby samples. Both hydrostatic and uniaxial stresses were applied to the specimens in the piezo-optic experiments.[296]

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[295] J. B. Saunders, "Production of near-perfect interferograms of variable visibility," *J. Res. NBS* **74C**, Nos. 1 and 2, 1-2 (1970).

[296] "Piezo-optic and thermo-optic properties of solid laser materials," *NBS Technical News Bulletin* August 1970, p. 177.

Measuring Laser Energy

Casting about in the mid-1960s for the most accurate method to measure the output energy of pulsed lasers, Donald A. Jennings developed the most confidence in calorimeters. He designed and built a calorimeter that incorporated an absorption cell containing an aqueous solution of copper sulfate, whose temperature was continually monitored by a thermocouple thermometer. He also developed two calibration schemes, one based on the known heat capacity of the absorption cell and the other on the substitution of known amounts of electrical heating to reproduce the final measured cell temperature. The two methods agreed within about 0.3 %.

Jennings employed the new apparatus to measure the output energy of a pulsed ruby laser operating at 694 nm. He found the calorimeter useful at laser energies as high as 30 J and peak power to 200 MW/cm^2.[297]

Before long, calorimetry was the standard method for laser-energy measurements. In 1969, Jennings teamed with E. Dale West, Kenneth M. Evenson, A. L. Rasmussen, and W. R. Simmons to summarize laser power and energy measurements in *NBS Technical Note 382.*

The pursuit of high-accuracy laser calorimetry was maintained by West and his colleague Kenneth L. Churney, who analyzed the theory of isoperibol calorimetry in 1970. The two scientists treated the measurements in terms of the first law of thermodynamics and the boundary value problem describing heat flow in the calorimeter. Their study pointed the way to design principles, minimization of experimental uncertainty, and methods for testing the validity of specific experiments.[298] Based upon the guidelines developed by West and Churney, a Boulder group—West, W. E. Case, A. L. Rasmussen, and L. B. Schmidt—designed, built, and evaluated a small reference isoperibol calorimeter for the measurement of laser energy. They outlined procedures to relate all measurements to NBS standards of voltage, resistance, and frequency, offering the careful user maximum systematic error levels not to exceed 1 %.[299]

A handy, on-the-spot measurement of the output energy of solid-state lasers, accurate within about 3 % for output energy levels as high as 100 J, was made possible by Arthur H. Neill and John A. Mitchell of the Electronic Technology Division. Neill designed and developed the device and Mitchell fabricated it into a manageable box weighing less than 25 kg.

The calorimeter was composed of an absorber, a light-dispersing reflective cone of aluminum enclosed within a blackened cylinder designed to retain nearly all of the laser energy, and a heat sink which provided reference cold junctions for a ring of series-connected thermocouple thermometers arranged on the absorber. In operation, a

[297] D. A. Jennings, "Calorimetric measurement of pulsed laser output energy," *IEEE Trans. Instr. Meas.* **IM-15**, No. 4, pp. 161-164 (1966).

[298] E. D. West and K. L. Churney, "Theory of isoperibol calorimetry for laser power and energy measurements," *J. Appl. Phys.* **41**, pp. 2705-2712 (1970).

[299] E. D. West, W. E. Case, A. L. Rasmussen, and L. B. Schmidt, "A reference calorimeter for laser energy measurements," *J. Res. NBS* **76A**, No. 1, 13-26 (1972).

Arthur H. Neill, Jr. of the NBS Electronic Technology Division measured the output energy of a solid state laser, using a portable calorimeter that he developed in 1970.

single laser pulse was intercepted by the calorimeter and the thermocouple output provided an energy value for the pulse. Calibration of the device showed it to be accurate within about 2.8 %.[300]

Oscillator Strengths and Transition Probabilities

Accurate determinations of the abundance of iron in the sun were significant to the development of models of the solar atmosphere. Previous determinations indicated, surprisingly, that the fraction of iron present in the sun's photosphere was much smaller than in the corona. The oscillator strength, or f-value, of iron was a key component to resolving the unexpected difference. Studying the question, J. Mervyn Bridges and Wolfgang Wiese found substantial discrepancies between recent f-values for neutral iron and those listed in older tables.

The two atomic physicists remeasured the iron f-values, using a plasma-arc source which they modified to stabilize the light intensity. Careful introduction of iron vapor and comparison and calibration of the resulting line intensities yielded greatly improved determinations of the f-values for iron. In some cases, earlier values were found to be erroneous by factors of 20! Using the new NBS values, astronomers quickly were able to correct estimates of the iron abundance in the solar photosphere by a factor of about 10, resolving the puzzling discrepancy.[301]

[300] A. H. Neill, Jr., "High-energy light detector for use with pulsed ruby and glass lasers," *Appl. Opt.* **9**, No. 10, 2392-2393 (1970).

[301] J. M. Bridges and W. L. Wiese, "Transition probabilities for the prominent red lines of Ne I," *Phys. Rev.* **A2**, No. 2, 285-293 (1970).

The work with Bridges was only one of many for Wiese. He was awarded the Department of Commerce Gold Medal in 1971 for his contributions to atomic and plasma physics. Like many Bureau scientists, Wiese showed leadership in two ways; by personal research and by collaborating with others on larger projects. During this period, his individual publications included two significant papers: one describing the relation between atomic oscillator strength and especially nuclear charge, and a second reviewing the field of transition probabilities.[302] With A. W. Weiss and Mervyn Bridges, he presented two papers on atomic oscillator strengths.[303] With Bridges, Richard L. Kornblith, Daniel E. Kelleher, and Jeffrey R. Fuhr, he wrote one paper and an *NBS Special Publication* on transition probabilities.[304] And with Kelleher, he discussed the possible role of slight systematic shifts in certain stellar spectra in accounting for the redshift in white dwarf stars.[305]

Physical Standards Research

In this section, we present accounts of standards in the areas of time and frequency, viscosity, millimeter-wavelength radiation, microwave power, voltage, and mass.

Telling Time by Television and by Satellite

A new wrinkle in convenience for time-synchronization signals from NBS was described by personnel of the Time and Frequency Division during 1970-71. The innovation involved the use of live network-television broadcasts. Short discussions of the principles of the technique were given by Dicky D. Davis, James L. Jesperson, and George Kamas[306] in a letter to the *IEEE Proceedings*, and, in fuller detail, by Davis and Byron E. Blair in collaboration with James F. Barnaba, a colleague from the Newark Air Force Station.[307] The new method promised 10 μs accuracy in time-synchronization of certain clocks without the necessity of carrying a portable clock to each participating site.

[302] W. L. Wiese, "Dependence of atomic f-values on nuclear charge," chapter in *Beam Foil Spectroscopy II* (New York: Gordon and Breach, 1968) pp. 386-406. Also see "Systematic trends of atomic oscillator strengths in isoelectronic sequences," *Appl. Opt.* **7**, No. 12, 2361-2366 (1968). See also W. L. Wiese, "Atomic transition probabilities—a survey of our present knowledge and future needs," *Nucl. Instr. Methods* **90**, 25-33 (1970).

[303] W. L. Wiese and A. W. Weiss, "Regularities in atomic oscillator strengths," *Phys. Rev.* **175**, No. 1, 50-65 (1968). See also J. M. Bridges and W. L. Wiese, "The oscillator-strength scale for Fe I," *Astrophys. J.* **161**, L71-L75 (1970).

[304] W. L. Wiese, J. M. Bridges, R. L. Kornblith, and D. E. Kelleher, "Transition probabilities for prominent Ar I lines in the near infrared," *J. Opt. Soc. Am.* **59**, No. 9, 1206-1212 (1969). See also J. R. Fuhr and W. L. Wiese, "Bibliography on atomic transition probabilities, July 1969 through June 1971," *NBS SP 320*, Suppl. 1, September 1971, 67 pp.

[305] W. L. Wiese and D. E. Kelleher, "On the cause of the redshifts in white-dwarf spectra," *Astrophys. J.* **166**, L59-L63 (1971).

[306] "The use of television signals for time and frequency dissemination," D. D. Davis, James L. Jesperson, and G. Kamas, *Proceedings of the IEEE*, June 1970, pp. 931-933.

[307] D. D. Davis, Byron E. Blair, and James F. Barnaba, "Long-term continental U.S. timing system via television networks," *IEEE Spectrum* **8**, August 1971, pp. 41-52.

Originating from a technique developed in Europe, the synchronization method involved the insertion of a time code into the live broadcast emanating from the New York transmitter of station ABC, CBS or NBC. The time signal was generated by a highly precise clock maintained by each of the stations in conjunction with their broadcast needs; it was inserted into a particular horizontal line of the broadcast display. As the broadcast was transmitted directly to local receivers or through microwave links to receivers across the United States, the coded time signal went along with it.[308]

Users of similarly precise clocks (those already known to be accurate within one television frame—about 30 ms) could build a decoder circuit as described by Davis, Blair and Barnaba for under $200. Using the decoder, they could read the network time signal and compare it with their own clock, just as NBS employees could compare the network time signal with their master atomic clock. NBS scientists had explored the method as a means of comparing the atomic clocks maintained at WWV in Washington, WWVB in Boulder, and WWVL in Fort Collins, Colorado, as well as comparing these clocks with those maintained at the Naval Observatory in Washington and at Newark Air Force Station in Ohio.

Having measured the difference in reading between any particular clock and the network clock, it was still necessary to interpret the difference so as to evaluate the actual discrepancy between the clocks and, more importantly, to determine the deviation of each of the clocks from the NBS master time clock. This step required a detailed accounting of the time delay resulting from the particular path taken by the network broadcast. Use of the microwave television link involved a delay of about 3 μs per km; the Bureau staff assisted the owners of clocks in remote areas in determining the time-delay corrections needed to relate the television synchronization signals to time differences from the NBS atomic clock.

Many users of the Bureau's time service had no need of the 10 μs accuracy level that the new system could provide. However, those users who did need the service could utilize it without the expense and delay of transporting an atomic clock to their location.

Another breakthrough in time and frequency dissemination occurred on the heels of time-by-television: time-by-satellite.

Beginning in 1971, the NBS time and frequency signals—ordinarily available only through the Bureau's high-frequency radio broadcast—were transmitted also by signals relayed from the National Aeronautics and Space Administration's ATS-3 satellite. The signals were based upon the NBS Frequency Standard and the NBS Coordinated Universal Time Scale that were maintained at the Boulder laboratories of the Time and Frequency Division. The broadcasts were part of an experiment in dissemination of the Bureau's WWV T&F information. First results of the experiment were reported by D. Wayne Hanson and Wallace F. Hamilton.[309]

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[308] A brief discussion of the use of commercial television for broadcasting time and frequency information can be found in "Boulder experimental TV time and frequency system," *NBS Standard,* Vol XVI, No. 5, May 1971, p. 7.

[309] D. W. Hanson and W. F. Hamilton, "Satellite broadcasting of WWV signals," *IEEE Transactions on Aerospace and Electronic Systems,* **AES-10**, No. 5, pp. 562-573, September 1974.

The ATS-3 was not the first satellite to be involved in time and frequency broadcasts; that honor belonged to the Telstar satellite, used in 1962 to compare the clocks at the U.S. Naval Observatory with those at the Royal Greenwich Observatory in England. The satellite technique proved accurate within 1 μs, sometimes better, on an experimental basis.

There was one obvious advantage to the use of the ATS-3 satellite to broadcast time and frequency information: the signals could be received over nearly 40 % of the earth's surface—in North America, South America, much of the Atlantic and Pacific Oceans, and in parts of Europe and Africa. Questions to be answered about satellite transmission included the cost of the system to the users and the accuracy with which the information could be delivered.

The ATS-3 satellite was placed in a geostationary orbit at approximately 70° west longitude. The signals were sent to the satellite at a frequency of 149.245 MHz; its transponder converted the frequency to 135.625 MHz, amplified it, and retransmitted it to all who cared to listen. The timing format consisted of tones, ticks, a time code, and voice announcements, familiar to those users who received the information over WWV and WWVH. Two 15-minute broadcasts were sent each day, beginning at 1700 hours and 2330 hours, Greenwich Mean Time.

Periodical adjustments were made in the broadcasts to improve their usefulness as a dissemination service of NBS.

The Bureau staff calibrated receivers for use with the broadcast experiment, two for sites in North America (Boulder and the Air Force Cambridge Research Laboratory) and two for South America (Smithsonian Astrophysical Laboratories in Arequipa, Peru and in Natal, Brazil). Calibrated cesium atomic clocks, synchronized to Boulder time by portable calibration clocks, were used to evaluate the time-delay involved in the satellite signals (typically about 0.25 s) as well as the effectiveness of the system. Delays occurred because of the length of the broadcast path, transit time in the electronic equipment, and atmospheric conditions. Uncertainties in these delay components placed limits on the accuracy of the dissemination method, as did "wandering" from its nominal position by the satellite itself. Changes in the satellite position resulted in time differences of approximately 1 μs for each 300 m of motion.

During 1972 the experimental broadcasts were received and the delays compared to predicted values. The discrepancies reached magnitudes no larger than 30 μs, a distinct improvement over typical uncertainties of 1 ms found by use of the earthbound radio signals. In addition, the satellite signals presented a "cleaner" electromagnetic pattern than did the earthbound broadcasts. The best news of all was that the cost of satellite reception appeared to be very comparable with the $100-$500 cost of WWV/WWVH receiving equipment.

On the basis of this experiment, time-by-satellite seemed poised to join the panoply of time-dissemination methods—the wristwatch, the telephone, high-frequency (eg., WWV) radio broadcasts, low-frequency (eg., Loran-C) broadcasts—but with improved accuracy available over a large portion of the globe. James L. Jesperson and Lowell Fey neatly summarized these and other techniques for transferring knowledge of time and frequency during this period,[310] as did Jesperson, Byron E. Blair, and Lawrence E. Gatterer in a more technical article.[311]

Before departing from the subject of time and frequency for the moment, we must mention the publication, in 1972, of *Special Publication 300,* volume 5. It contained reprints of more than 80 papers published during the period 1960-1969, separated into sections on standards, time scales, dissemination, statistics, and selected references.[312]

How Well Can We Measure Viscosity?

Viscosity measurements had been around a long time, but there was something wrong with them—they relied on an assumed value for the viscosity of water as a reference. If there were biases (systematic errors) in the water-viscosity measurement, all measurements would be erroneous.

What to do to evaluate the absolute uncertainty of viscosity measurements? Of course—devise two significantly different techniques for absolute viscosity measurement and compare the results. Accordingly, Robert W. Penn, Hobart S. White, and Elliot A. Kearsley replaced the traditional capillary method with two new methods that would, at least, exhibit different biases.

Penn and Kearsley assembled a three-cornered flow channel by clamping two 1 m long stainless-steel rods together, then clamping a glass flat across the two rods. An equation was derived for kinematic viscosity in the resulting geometry. Pressure taps, a standpipe at the entrance to provide calculable entry pressure, a sampling system at the exit, and careful temperature control completed the apparatus. Viscosity measurements were made on a light oil. Using a well-established relation between the viscosity of the light oil and the viscosity of water, the authors derived a value of (1.001 ± 0.001) cP at 20 °C for water.[313]

Meanwhile, White and Kearsley built a 10 cm diameter hollow nickel sphere with a smooth interior surface. The sphere was designed to be filled with the test fluid, hung from a wire, and set into oscillation by applying a small torque. The two derived an equation relating the period of oscillation to the viscosity of the fluid. Timing of the oscillation was accomplished electronically. Again, the system was placed under careful temperature control. Their measurements, performed on a different light oil, could be corrected to yield a value for the viscosity of water. The value so deduced was $(1.006 + 0.001)$ cP. This value was about 0.5 % higher than the one obtained by the channel-flow technique.[314]

[310] James L. Jesperson and Lowell Fey, "'Time-telling' techniques," *IEEE Spectrum* **9**, pp. 51-58, May 1972.

[311] James L. Jesperson, Byron E. Blair, and Lawrence E. Gatterer, "Characterization and concepts of time-frequency dissemination," *Proc. IEEE* **60**, No. 5, pp. 502-521, May 1972.

[312] B. E. Blair and A. H. Morgan, Editors, "Precision Measurement and Calibration: Selected papers on Frequency and Time," *NBS Special Publication 300,* Vol. 5, 565 pp., June 1972.

[313] R. W. Penn and E. A. Kearsley, "An absolute determination of viscosity using channel flow," *J. Res. NBS* **75A**, No. 6, 553-560 (1971).

[314] H. S. White and E. A. Kearsley, "An absolute determination of viscosity using a torsional pendulum," *J. Res. NBS* **75A**, No. 6, 541-551 (1971).

Elliot Kearsley inspected the height of the liquid inside a hollow sphere that, when excited, became a rotational pendulum, turning first in one direction and then in the other. It could be used to make absolute viscosity measurements, the viscosity of the sample liquid being calculated from observed parameters, including the period of oscillation.

Robert S. Marvin, comparing the two experiments with previous determinations, suggested that systematic errors remaining in viscosity measurements limited their accuracy to about ±0.25 %, a much larger figure than ±0.1 %, the irreproducibility of carefully performed measurements.[315]

New Calibration Service for Millimeter Waves

The Boulder Radio Standards Engineering Division announced in February 1972 the initiation of a calibration service to extend their microwave calibrations into the 55 GHz to 65 GHz range. Types of measurements provided included the following:

- Power, measured using a microcalorimeter, accurate at the ±3 % level.
- Attenuation at the level of ±0.05 dB per 10 dB, from 0 dB to 50 dB.
- Impedance (measured as the reflection coefficient) over the range 0.001 Γ to 1.0 Γ.
- Antenna gain, measured both indoors and out.
- Noise, to an accuracy of 2.3 %, depending on the equipment involved.

The new service was operated by Frances X. Ries.

Changing Time by Leap Seconds

All early efforts towards more accurate timekeeping were driven by the desire for better navigation. Therefore, the most useful clocks were those that most closely represented the earth's rotation rate. *Greenwich Mean Time* became the official source of earth-based timekeeping in the 1840s, and it held its position as the world standard of time until January 1, 1972. Ingenious pendulum clocks offered timekeeping accuracy at the level of about one part in ten million. Quartz oscillator clocks performed even better.

When Harold Lyons, Chief of the NBS Microwave Standards Section, began to use an absorption line of ammonia as an "atomic clock" in 1948, he opened the door to a new level of accuracy in timekeeping. Also lurking behind that door was an inevitable collision with *Greenwich Mean Time.*

The idea of basing time and frequency measurements on atomic transitions was revolutionary. Unlike pendulum clocks or quartz crystals, all ammonia atoms were alike; the frequency of the chosen transition was invariant. "Atomic clocks" made anywhere would, in principle, keep exactly the same time. More advanced clocks based on the measurement of a 9192 MHz transition in atomic beams of cesium agreed within 2 parts in 10^{11} by 1960.[316]

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[315] R. S. Marvin, "Accuracy of measurements of viscosity of liquids," *J. Res. NBS* **75A**, No. 6, 535-540 (1971).

[316] R. E. Beehler, R. C. Mockler, and C. S. Snider, "A comparison of atomic beam frequency standards," *Nature* **187**, August 20, 1960, pp. 681-682. According to Bragaw and Snyder, *Achievements in Radio,* p. 301, other Bureau staff members who participated in the early work on atomic clocks included Jesse E. Sherwood, Robert N. McCracken, Richard C. Mockler, David W. Allan, James A. Barnes, R. Lowell Fey, David J. Glaze, Donald W. Halford, F. Russell Petersen, Jack B. Snider, Richard L. Strombotne, Henry F. Salazar, and Arthur E. Wainwright.

The very high accuracy reached by the atomic clocks made painfully obvious the fact that the earth's rotation was not uniform, but instead varied by a few thousandths of a second a day (about one part in 10^8). The question became one of how to take advantage of the accuracy of modern atomic clocks while still keeping terrestrial clocks in time with the earth's movements. Various techniques involving Ephemeris Time, Universal Time, and "rubber seconds" were not successful.

The eventual resolution of the earth-clock *vs* atom-clock problem involved a compromise. On January 1, 1972, the International Bureau of Weights and Measures began to administer a new time scale, *Coordinated Universal Time,* or UTC. The accumulation of time on the UTC followed the atomic clocks. However, a one-second adjustment to the UTC would be made whenever earth time deviated as much as one second from atomic time. Because of the similarity to the "leap year" concept, the one-second adjustments were called "leap seconds."[317]

High-Level and Wide-Range Power Measurements

New techniques for the measurement of continuous-wave microwave power at high levels and for the measurement of power over wide ranges of power and frequency were developed by members of the Radio Standards Engineering Division in Boulder.

W. E. Little, K. E. Bramall, and E. Andrusko, collaborating with R. Gray of the Rome [New York] Air Development Center of the U.S. Air Force, demonstrated the feasibility of measuring with unprecedented accuracy the output of a 60,000 W, 8 GHz klystron amplifier. Using standard NBS microwave power calibration equipment with a new type of power divider, the group visited the Air Force installation and measured the large radar source with an estimated uncertainty less than 4 %.[318] It was considered important to refine the measurement of microwave power—commonly only accurate to 10 % at that time—to avoid the "overdesign" of equipment as well as to minimize hazards from radar installations, microwave ovens, and communications gear.

In a separate project, R. A. Lawton, C. M. Allred, and P. A. Hudson developed a new technique useful for the measurement of power levels as low as 10^{-14} W over the entire radio-frequency range.[319] A standard power meter was employed in the process to determine a reference level, then a set of precision attenuators and a null detector were used to obtain power values with uncertainty levels of about 0.5 % to 1.5 %. These results represented an improvement over previous accuracy figures by factors of 2 to 6. It was expected that the new method could be used to measure power levels as high as 100 kW, and to be useful in the calibration of detectors, receivers, radiometers, and other instruments.

[317] James Jespersen and Jane Fitz-Randolph, "From sundials to atomic clocks: understanding time and frequency," *NBS Monograph 155*, December 1977, 175 pp.

[318] "High-level microwave power measurements," *NBS Technical News Bulletin,* July 1970, pp. 146-147.

[319] R. A. Lawton, C. M. Allred, and P. A. Hudson, "A wide-range cw power measurement technique," *IEEE Trans. Instr. Meas.* **IM-19**, No. 1, 28-34 (1970).

Analyzing High-Intensity Electric Fields

In studies of liquid dielectrics, where distortions of the electric fields by space charge made analytical determinations of the field distributions difficult or impossible, a new technique devised by Esther C. Cassidy and Harold N. Cones of the Electricity Division permitted accurate mapping of field intensity between electrodes immersed in liquid dielectrics.

The new method was based on the observation of the Kerr effect in nitrobenzene-filled cells. An expanded beam from a helium-neon laser was passed through a polarizer prior to entering the Kerr cell, then detected after passing through a second polarizer. The effect of high voltages on the refractive index of the nitrobenzene rendered the field profile visible in cases where the fields were non-uniform. Mapping of the fringe patterns allowed space-resolved measurements of relative field strength, actual field strength, and electrical potential. Visual examination could immediately detect regions of high electrical stress, where arcing and breakdown were likely.

The new technique was expected to lead to a better understanding of the behavior of dielectrics exposed to high-intensity electric fields.[320]

New Mass Standards from Ion Exchange Beads

David H. Freeman came to the Bureau's Analytical Chemistry Division in 1965, young but highly trained in the science of ion exchange. By 1968 Freeman was chief of the Separation and Purification Section of the division.

In March of that year, he spoke on ion exchange during an NBS *Symposium on Future Standards For Analysis,* staged by the Institute for Materials Research as part of the *Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy* (held, strange as it may seem, in Cleveland, Ohio, in 1968). Freeman predicted that ion exchange resins in the form of small, spherical particles would soon be perfected as mass standards at the Bureau. The advantage of the spherical beads lay in their chemical uniformity and the fact that they could be implanted with electrically charged counterions, either singly or in combination. Each bead's counterion content was directly related to the bead diameter, said Freeman, so that careful measurement of the bead diameter could produce a chemical microstandard.

Freeman quoted the results of a recent National Academy of Sciences-National Research Council survey of 78 analytical laboratories to indicate the types of activities in which such standards were expected to become useful. These included the convenient setting of analytical detection limits, microscale calibration of chemical measurements, flux standards for neutron irradiation, microspectrophotometric absorption standards, electron probe microanalysis, and mass spectrometry.

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[320] E. C. Cassidy and H. N. Cones, "A Kerr electro-optical technique for observation and analysis of high-intensity electric fields," *J. Res. NBS* **73C**, Nos. 1 and 2, 5-13 (1969).

By 1970 the first of the new standards was ready. Freeman, Lloyd A. Currie, Edwin C. Kuehner, Herbert D. Dixon, and Rolf A. Paulson described their development and characterization in a detailed article in the journal *Analytical Chemistry.*[321] Beads were available with diameters in the range 1 mm to 1 μm, as measured by photomicroscopy and electron microscopy. These diameters corresponded to masses in the range 10^{-3} g to 10^{-12} g. Encapsulation of both sodium and calcium particles had been accomplished. Samples of well-characterized beads were immediately made available through the Office of Standard Reference Materials.

Clearly, work to take full advantage of the new microstandards was still in the early stages, but ground had been broken in yet another standards area.

Director Lewis Branscomb gave the work on new mass standards high praise:

> This advance in measurement science illustrates the way sophisticated scientific work helps solve major problems affecting our Nation. Inability to measure accurately the minute quantities of pollutants in air and water is a tremendous obstacle in all anti-pollution efforts. This significant step along this road will help make both research and regulation easier and more effective.[322]

A New Standard for Voltage Ratios

In 1970 Ronald F. Dziuba and Bernadine L. Dunfee developed a new electrical standard. Built especially for dc and low-frequency ac calibrations, the new standard was capable of evaluating voltage ratios involving voltages as high as 1000 V with uncertainty levels as low as 0.2 ppm.

The standard was a stable, guarded unit enclosed in a sealed, thermostated container. The two scientists provided discrete ratios from 1:1 to 1000:1. Each successive ratio was measured by a substitution method and by satisfying the conditions of the series-parallel principle. A measuring network and the techniques to be followed in the use of the standard were important parts of the measuring system.[323]

Forest K. Harris Retires

Forest K. Harris "retired" from the Electricity Division, where he had served as chief of the Absolute Electrical Measurements Section, in April 1971. In retirement, however, he continued to assist the Division as a consultant. In June 1972, the Institute of Electrical and Electronic Engineers honored Harris with the award of the Morris E. Leeds prize for:

[321] David H. Freeman, Lloyd A. Currie, Edwin C. Kuehner, Herbert D. Dixon, and Rolf A. Paulson, "Development and characterization of ion-exchange bead microstandards," *Anal. Chem.* **42**, No. 2, 203-209 (1970).

[322] "Ion exchange beads: the "micromini" calibrators," *NBS Tech.* Newa Bull., April 1970, p 82.

[323] R. F. Dziuba and B. L. Dunfee, "Resistive voltage-ratio standard and measuring circuit," *IEEE Trans. Instr. Meas.* **IM-19**, No. 4, pp. 266-277 (1970).

> A lifetime of making outstanding advances in the science of high accuracy electrical measurements, and of stimulating further advances through his teaching, authorship, and committee activity.[324]

A Bureau staff member since 1925, Harris was no stranger to awards for excellent scientific work. In 1955, he received the DoC Meritorious Service Award for his book *Electrical Measurements,* a classic in its field. In 1967, he received the NBS Edward B. Rosa award for his contributions to the development of standards for electrical measuring instruments.

Problems with an Unseasoned Temperature Scale

We mentioned in Chapter 1 the *Treaty of the Meter,* signed in 1875 in Paris by the United States and some 16 other nations. Agreements on new international measurement standards involved national laboratory staffs throughout the world, as well as the International Bureau of Weights and Measures and other Treaty organizations. Usually, new standards were suggested to the International Committee for Weights and Measures (CIPM) by the appropriate Consultative Committee, composed of working scientists. But this was not always the case.

In 1968, the international Consultative Committee for Temperature (CCT) could no longer resist the call of the CIPM to amend—if not replace entirely—the *International Practical Temperature Scale of 1948.* The result was a new temperature scale that was unready for service.

The CCT had been loath to call for a new scale, because its members felt that many of the projects on fundamental thermometry that were needed for such an amendment were not yet complete. Although international bodies tend to accept progress in deliberate, measured doses, the CIPM—as recorded by Hugh Preston-Thomas later, when he was President of the CCT—had, for over a decade, dropped more and more pointed hints that the time for renovation or replacement of the IPTS-48 was at hand.[325]

Replacement of the 1948 temperature scale was considered an urgent matter primarily because of international programs involving temperatures beyond its lower limit. The most obvious of these concerned liquid hydrogen, used in the development of thermonuclear weapons and in NASA's rocketry. NASA also made extensive use of liquid helium as a coolant. At ordinary pressures, hydrogen is a liquid only below 20 K, and helium liquefies below 4.2 K; the lower limit of the 1948 scale was 90 K—above even the normal boiling point of nitrogen.

Thus it happened in 1968 that the CCT transmitted to the CIPM a tentative outline for a new temperature scale extending down to 14 K, a scale that one of its subcommittees had prepared during the previous year. The CIPM wasted no time in

[324] "Dr. Forest K. Harris to receive IEEE award," *NBS Standard* Vol. XVII, No. 3, April 1972, pp. 9, 15.

[325] H. Preston-Thomas, "The origin and present status of the IPTS-68" in *Temperature, Its measurement and Control in Science and Industry*, Vol. 4, H. H. Plumb, Editor-in-Chief, Instrument Society of America, 1972, pp. 3-14.

notifying members of the General Conference on Weights and Measures that a new scale was at hand. During the fall of the year, the 13th General Conference passed a resolution permitting the CIPM to promulgate the new scale, and delegates to the CIPM meeting separately but essentially simultaneously designated the tentative outline as the *International Practical Temperature Scale of 1968*. All that was wanting were a few details: a text that would prescribe the means by which temperatures on the new scale could be determined; some knowledge of the relation of the new scale to the 1948 version; and estimates of the uncertainties of the new scale with respect to thermo-dynamic temperatures in the various parts of its range.

It is a testament to the resourcefulness of the thermometrists involved that a complete text for the 1968 temperature scale was published early in 1969.[326] Rapid correspondence among laboratories that had developed provisional scales ranging from 14 K upwards produced the required extension to lower temperatures. New values, more in accord with the then-current perception of the thermodynamic scale, were assigned to fixed points throughout the new scale. Adjustments were made to calibration procedures for standard platinum resistance thermometers in the range 14 K to 904 K (–259 °C to 631 °C), for standard platinum *vs* platinum-rhodium-alloy thermocouple thermometers in the range 904 K to 1337 K (631 °C to 1064 °C), and for spectral radiance thermometers in the range above 1337 K.

But given the hurried nature of its production, it was no surprise that thermometrists quickly found inconsistencies in the 1968 temperature scale. Two of the earliest protests came from NBS.

John P. Evans and Sharrill D. Wood, convinced that platinum resistance thermometry might provide a better scale in the range 904 K to 1337 K than could be realized using standard thermocouple thermometers, carefully compared nine specially prepared platinum resistance thermometers with eight standard thermocouple thermometers.[327] They found the resistance thermometers considerably more reproducible than the thermocouple thermometers: uncertainties of about 0.004 K for the former, 0.025 K to 0.030 K for the latter. But of equal interest was a curious discrepancy—reaching 0.4 K in mid-range—between temperatures determined using simple quadratic interpolation schemes for the two types of thermometers from 904 K to 1137 K. These results would be mirrored in a major renovation to the 1968 scale, promulgated in 1990, when it was decided that a quadratic equation did not accurately portray the relationship between the electromotive force of a standard thermocouple thermometer and thermodynamic temperatures.

A more direct attack on the accuracy with which the 1968 temperature scale represented thermodynamic temperatures came from Leslie A. Guildner, Richard L. Anderson, and Robert E. Edsinger. These scientists, continuing an NBS gas thermometry program started decades previously, found a surprisingly large discrepancy at

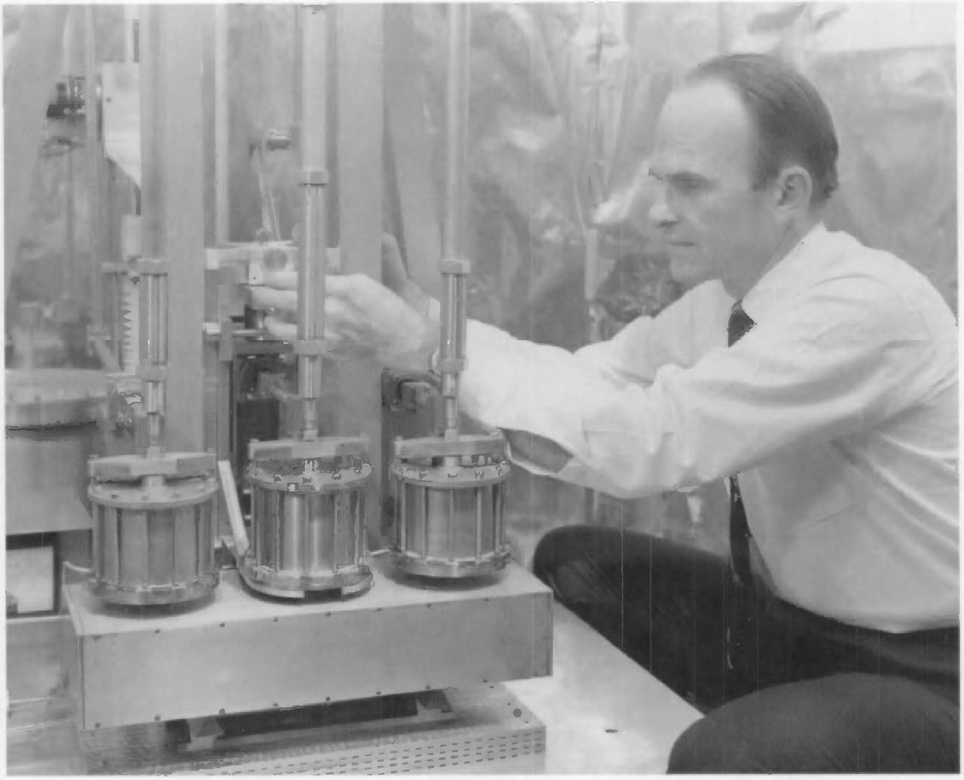
[326] "International Practical Temperature Scale of 1968," *Metrologia* **5**, 35 (1969).

[327] J. P. Evans and S. D. Wood, "An intercomparison of high temperature platinum resistance thermometers and standard thermocouples," *Metrologia* **7**, No. 3, pp. 108-130 (1971).

Sharill Wood welded platinum wires to fabricate a platinum resistance thermometer intended for use at temperatures as high as 1100 °C.

373 K, only 100 K above the major defining temperature of the 1968 scale provided by the triple point of water.[328] Instead of differing by 100 K exactly, as assumed in constructing the IPTS-68, the three Bureau authors found that the steam point was only 99.973 K above the ice point. The discrepancy, 0.027 K, was five times larger than the estimated thermodynamic uncertainty of the 1968 scale at that temperature.

[328] L. A. Guildner, R. L. Anderson, and R. E. Edsinger, "Effects of sorption on the realization of the thermodynamic scale," pp. 313-322 in *Temperature, Its Measurement and Control in Science and Industry*, 4, Harmon H. Plumb, editor-in-chief, Part 1 (Pittsburgh: Instrument Society of America, 1972).



Leslie A. Guildner adjusted the extremely accurate mercury manometer that he developed with colleagues Richard L. Anderson and Robert E. Edsinger for use with the NBS gas thermometer.

The usefulness of the IPTS-68 reference temperatures was challenged by George Furukawa, John Riddle, and William Bigge of the Heat Division's Platinum Resistance Thermometer Calibration laboratory. They had employed the freezing point of tin (232 °C) as a reference temperature for the calibration of platinum resistance thermometers for many years. They found it substantially more reliable than the boiling point of water (100 °C), specified as a calibration temperature in the IPTS-68.[329]

[329] George T. Furukawa, John L. Riddle, and William R. Bigge, "Investigation of freezing temperatures of National Bureau of Standards tin standards," pp. 247-263 in *Temperature, Its Measurement and Control in Science and Industry* 4, 1972, H. H. Plumb, Editor.

The authors collaborated with the NBS Standard Reference Materials program in evaluating tin freezing-point temperature as part of the issuance of two grades of tin as SRM-42G (10 ppm maximum impurities) and SRM-741 (1 ppm maximum impurities).[330] They carefully filled several freezing-point cells with samples of each purity. The results showed consistency of samples of a given purity within 10^{-4} °C; the less-pure tin was found to exhibit a slightly lower freezing temperature (5×10^{-4} °C) than the purer samples. On balance, tin appeared to be a good candidate for a reference temperature for an eventual replacement temperature scale. In fact, their work was adopted as part of the new scale that was promulgated in 1990.

Although the 1968 temperature scale would survive for 22 years, its eventual replacement was almost a certainty from the date of its birth.

[330] Robert L. Powell of the NBS/Boulder Cryogenics Division also participated in the certification of the tin samples by determining the ratio of the electrical resistivity at 0 °C to that at 4.2 K.

CHAPTER THREE

A NATION IN TROUBLE; AN AGENCY IN CHANGE
(May 1972–June 1975)

Early in 1972, while Lewis Branscomb and his colleagues were eagerly contemplating excellent prospects for a large funding increase for NBS, Richard Nixon and his colleagues were eagerly contemplating excellent prospects for his re-election to the presidency of the United States. For both groups, joy would be short-lived.

At NBS, Branscomb's success in revising the image of the Bureau gave promise of greater importance for the agency and the prospect of enough operating and equipment funds to work in something like the circumstances enjoyed in other major scientific laboratories. The budget put forth in March reflected the largest peace-time increase ever requested for the Bureau, and most of it was appropriated by the Congress later in 1972.[1]

In the White House, President Nixon had every reason to expect re-election: by March, only 95,000 American troops remained in Vietnam—less than one-fifth the number there in 1969; a triumphant trip to Moscow in May, following an equally triumphant trip to China in February, burnished the image of the President as a powerful world leader; the economy was temporarily in fine shape, thanks in large measure to careful priming by the Administration; and best of all, the President's political opposition was in disarray.[2]

As the year wore on, however, unwelcome events clouded the bright prospects for both NBS and the President.

In April of 1972, almost before the ink was dry on the House Appropriations Subcommittee hearings transcript, NBS staff members learned that Branscomb would leave the Bureau at the President's earliest convenience. Not long after, some $13 million of the Bureau's new-found wealth went a-glimmering, a hapless victim of an Executive-Branch economy drive. Coping with these problems—at least until the elections were over—became the duty of Lawrence Kushner, who was designated Acting Director of NBS.

In June of 1972, a bungled burglary of the Democratic National Committee offices in the Watergate complex presented President Nixon with a small problem that he immediately turned into a major problem.

President Nixon's small problem was that the apprehended burglars had acted at the behest of G. Gordon Liddy and E. Howard Hunt, operatives for the Committee to Re-Elect the President; not only that, but they were "Plumbers," a group formed by the White House to stop information leaks by any means available.

[1] House Appropriations Subcommittee hearings, April 20, 1971, pp. 1117-1140; also the hearings on March 28, 1972, p. 1077; also the hearings on April 17, 1973, p. 772.

[2] James T. Patterson, *Grand Expectations* (New York: Oxford University Press, 1996), Ch. 24.

The Watergate burglary, as crimes go, was no big deal. The fact that the burglars could be connected with the White House, however, interested the Federal Bureau of Investigation. The President, worried about the effect on the coming elections of any unsavory revelations by the burglars, ordered H. R. Haldeman, one of his top aides, to instruct the Central Intelligence Agency to intervene in the case and to demand that the FBI drop its investigation.

This action, constituting obstruction of justice, transformed the small problem into a large one. As time went on, new illegal actions and the accidental revelation of unrelated misdeeds made the problem larger and larger.[3]

Seeking a New NBS Director

The resignation of Lewis Branscomb as Director of NBS after less than three years in that office surprised and puzzled the technical community both inside the Bureau and beyond. The bright future envisioned by the NBS staff suddenly became cloudy and uncertain. The eloquent voice and restless personality, so promising in terms of leadership within the Bureau and so visible in the Nation's scientific establishment and in Congress, passed like a shadow with Branscomb's letter of resignation to President Nixon on April 4, 1972.[4]

An editorial in *Science* magazine summarized Branscomb's role for NBS with the comments that he had ". . . aroused the low-profile and somewhat sleepy agency to eminence . . ." Branscomb, Nicholas Wade wrote, had brought ". . . recognition of its potential as the government's instrument for stimulating industrial technology. . . "[5]

Branscomb's departure was a great disappointment to Allen Astin. Astin had persevered as Director through trying and occasionally unpleasant times. He had accepted his problems as they came, always placing the welfare of NBS above any personal desire or need. It was galling to think that his carefully nurtured choice as successor might have been undone by the mere offer of more money—the type of temptation that confronted first-rank Bureau scientists continually.

The matter was not as simple as wages to be earned for a day's work, although the salary increase offered to Branscomb by International Business Machines, Inc. was indeed substantial. There was the job itself—technical direction of a $500 million research laboratory and the opportunity to serve as technical spokesman for one of the greatest of the high-tech corporations. At IBM, Branscomb could influence the course of technology at the highest level; certainly this was a challenge to his desire to make a mark on the technical life of the United States.

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[3] Stephen E. Ambrose, *Nixon, Volume Three: Ruin and Recovery, 1973-1990* (New York: Simon & Schuster, 1991), Ch. 1.

[4] *NBS Standard*, Special Edition April 20, 1972. The four-page issue contains a note on Branscomb's departure and his temporary replacement by Lawrence M. Kushner, Branscomb's letter to President Nixon, Nixon's letter of acceptance, and excerpts from Branscomb's announcement to Bureau division chiefs.

[5] N. Wade, "NBS Loses Branscomb to IBM," *Science* **176**, p. 147 (April 10, 1972).

Besides the pull of an influential, well-paid position, there was also the push of Branscomb's political mismatch with a Republican administration, which could have created problems at any moment. Branscomb knew that another promising Bureau leader, Edward Condon, had chosen earlier to resign the NBS directorship when his effectiveness was compromised by bad relations with Congress.[6] But whatever the why or wherefore, the end of Branscomb's short tenure left NBS without a director in May of 1972. *NBS Administrative Bulletin 72-25*, dated May 3, 1972, contains the single statement:

> Effective May 7, 1972, Dr. Lawrence M. Kushner, Deputy Director of the Bureau, will serve as Acting Director until a new Director is named.

"Until" turned out to be nearly one year, a delay that was occasioned in part by the coming Presidential elections, in part by the extraordinary distractions experienced during this period by the Nixon Administration.

No one would have been surprised had Kushner been named to succeed Branscomb as Director of NBS. A Princeton-trained physical chemist, Kushner had come to the Bureau in December of 1948.[7] He had been invited by James I. Hoffman to join the newly created Surface Chemistry Section of the Chemistry Division. Kushner soon had organized a small group, including Hoffman himself, Blanton C. Duncan, Willard D. Hubbard, Rebecca A. Parker, and A. S. Doan, that successfully investigated the fundamental properties of surface-active agents, primarily wetting agents and detergents.

Several years later, Kushner created a Metal Physics Section in the Metallurgy Division. In that effort and later as Chief of the Metallurgy Division, Kushner took steps to modernize the Bureau's scientific work in the area of metallurgy. He brought to NBS a group of scientists interested in the newer theories of alloying and dislocation, nuclear magnetic resonance in metals, and the use of the electron microscope. Some of the people initiating the new projects were Robert L. Parker (crystal growth), John R. Manning (diffusion), Arthur W. Ruff (x-ray and electron microscopy), Lawrence H. Bennett (nuclear magnetic resonance), and Roland DeWitt (imperfections in crystals).

In September 1964, Kushner was selected as one of the first 17 participants in a new Department of Commerce scientific exchange program. Dubbed the Commerce Science and Technology Fellowship, the program enabled budding technical leaders to view the department from new angles by working outside their own agencies.[8] During his fellowship, Kushner worked as a special assistant for legislation to J. Herbert Hollomon in the Office of the Assistant Secretary for Science and Technology. This experience gave Kushner an excellent perspective on the need for technological upgrading of U.S. industry.

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[6] Lauriston S. Taylor, Oral History, April 10, 1990.

[7] Lawrence M. Kushner, "An NBSer's Odyssey," *SAA Newsletter*, Vol. 98-2, June 1998, pp. 16-18.

[8] Press release, Office of the Secretary (Luther H. Hodges), U.S. Department of Commerce, September 9, 1964, issuance #G 64-140.

In 1969 Kushner became Deputy Director of NBS under Allen Astin. He remained in that post under Director Lewis Branscomb, accumulating more than three years experience in the position.[9]

Only one feature of Kushner's résumé could not particularly help him with the Nixon administration: although politically neutral, he was a registered Democrat.

Other reasonable choices as Branscomb's successor could be found among the senior managers at NBS, too. One was Ernest Ambler, Director of the Institute for Basic Standards, a scientist with two decades of service as a physicist in the field of cryogenics and in several management positions. Another was John D. Hoffman, Director of the Institute for Materials Research, who was a second-generation Bureau man (coincidentally, John's father, James I. Hoffman, had hired Lawrence Kushner). Hoffman had been a participant in the wartime Manhattan Project and, like Ambler, a staff member at NBS for 20 years. Hoffman was still active as a theorist in the field of polymer science. A third reasonable candidate for Director was Edward Brady, Associate Director for Information Programs. Brady, a physical chemist, had been recruited to NBS in 1963 expressly to become head of its then-new Office of Standard Reference Data. Prior to his Bureau tenure, Brady had served in the Manhattan Project and had spent 10 years devising nuclear programs for the General Electric Company. Yet another possibility was Howard Sorrows, Associate Director for Programs. Sorrows had been employed as an electronics scientist at NBS from 1941-52. Subsequently he had worked for the Office of Naval Research and the Naval Ordnance Laboratory and for Texas Instruments Corporation. In 1965 he had returned to NBS as Assistant to Gordon Teal, Director of the Institute for Materials Research.

In these scientists and in others not named here, there was breadth of scientific understanding, experience in management at NBS and elsewhere, and more than passing acquaintance with the national technical establishment. Leadership of the Bureau in the uncertain days ahead could logically have been placed in the hands of any of a whole group of senior NBS scientists.

Despite the ready availability of suitable leaders at NBS, the loss of Branscomb as Director was utilized by the Nixon administration as an opportunity to look elsewhere for a replacement. As an alternative to NBS career scientists, Arthur A. Bueche, a member of the Bureau's statutory Visiting Committee, suggested that NBS could benefit from a director who was an expert on technical communication—not necessarily an outstanding scientist, but someone who could "sell" the Bureau's programs to the Congress and to the technical public as well. Such a quality, which had been strong in Lewis Branscomb, was relatively rare among scientists.

Bueche had someone very specific in mind: Richard W. Roberts, Manager of Material Science and Engineering at the General Electric Research and Development Center in Schenectady, New York. Though he was a scientist (a physical chemist) by training, Roberts was known more as a good salesman. He was interested in technical management as a career. In 1973 Roberts was but 38 years of age. He had worked at NBS as a National Research Council post-doctoral associate during 1959-60,

[9] Lawrence M. Kushner, Oral History, June 7, 1988.

studying surface chemistry with Heat Division scientists Kurt Shuler, John McKinley, and Robert Ferguson. In 1960 he joined the General Electric Corporation. There he pursued studies of high vacuum and lubricants, publishing furiously for several years; then he turned to technical management with equal vigor. It was said by some that he had his eye on the position held by Arthur Bueche!

Bueche's efforts on behalf of Roberts were well-received at the Department of Commerce and at the White House. President Nixon apparently discussed the directorship of NBS with Roberts prior to the national elections in November 1972, although the formal nomination announcement was not made until December 20, 1972, after Nixon's re-election to the Presidency. The Senate Committee on Commerce held nomination hearings on January 29, 1973, and Roberts was confirmed on February 1.[10] He was sworn in on February 5, 1973.

Ernest Ambler later amplified the circumstances surrounding the selection of Roberts as NBS Director:

> Dick Roberts came to NBS because of Art Bueche. Bueche was head of the General Electric Company's Central Research Laboratory in Schenectady, and Roberts was one of his senior people. Bueche was also a member and ultimately Chairman of the NBS Statutory Visiting Committee.
> Bueche prided himself on his ability to communicate to top management the nature of the work of his laboratory and its importance and ultimate utility to the company. Roberts was a 'whiz' at the kind of 'show and tell' that Bueche's method demanded. By comparison Beuche thought we at NBS did an absolutely lousy job in marketing our wares to our bosses in the Government and thought Roberts was just the man to come down and show us how to fix this deficiency.[11]

A Second Term For Richard Nixon

One feature of 1972 went well for President Nixon; he and Spiro Agnew were easily re-elected, besting by a heavy margin their opponents, Senator George McGovern and Sargent Shriver. Shriver was a former head of the Peace Corps; he replaced Senator Thomas Eagleton as the Democratic vice-presidential candidate when revelations of the latter's history of mental illness caused McGovern to drop him from the ticket.

The Democratic Party, however, retained control of both houses of Congress. When the time came to question the legality of certain actions by President Nixon, the Democrats in Congress possessed the necessary power to pursue all the ramifications of the Watergate affair.

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[10] Nomination hearings for Roberts were held by the Committee on Commerce, 93rd Cong., First Sess., January 29, 1973, *Richard W. Roberts, to be Director of the National Bureau of Standards.* See also *Congressional Record—Daily Digest,* February 1, 1973, p. D-36.

[11] Ernest Ambler, "Historical Perspective: 1973-1989," in *NBS/NIST a Historical Perspective: A Symposium in Celebration of NIST's Ninetieth Anniversary,* March 4, 1991, Karma A. Beal, Editor, *NIST Special Publication 825,* April 1992, p. 31.

Thanks to Nixon's practice of tape-recording White House conversations, we know a great deal about how he was able to perform his presidential duties while at the same time pursuing his enemies with no regard for the law. It is instructive—nay, necessary—to take note of both facets of this interesting President.

"Watergate" and the Loss of a President

By the time that a replacement for Lewis Branscomb was nominated, the Nixon presidency had already been damaged seriously by the Watergate affair. Always suspicious, always determined to be decisive and tough, President Nixon had ensured himself at least a small problem by creating the "Plumbers," whose original charter was expanded as necessary to further the Administration's political goals. As noted above, Nixon also installed eavesdropping equipment to tape conversations and meetings in the White House.

Unfortunately, Nixon fell into the trap of denying all while failing to destroy tape-recorded evidence, which he presumed he could keep with impunity for later "historical" use. On February 7, 1973, a seven-member select committee of the U.S. Senate was established to investigate political espionage, including the Watergate break-in.

In a painfully slow process which lasted until August of 1974, the unfortunate details of Nixon's schemes were gradually uncovered by the Senate committee. The results showed a President so consumed with distrust that he not only countenanced lawlessness within his administration but demanded it of his personal staff.

In October of 1973, Vice President Agnew resigned his office rather than face trial on charges of bribery, extortion, and income-tax evasion that dated back to his days as Governor of Maryland but also extended into his term as Vice President. Agnew's resignation was forced by Elliot Richardson, only months earlier named Attorney General by Nixon after the resignation of Richard Kleindienst. Richardson had acted quickly upon seeing the evidence against Agnew, in order to eliminate the possibility that Nixon might be succeeded by a man soon to be prosecuted on felony charges.[12] Required by the 25th amendment to the U.S. Constitution to quickly nominate a replacement Vice President for confirmation by a simple majority of both houses of Congress, Nixon nominated Gerald R. Ford of Michigan, Minority Leader of the House of Representatives, a man whom the Congress could happily confirm.

On the same day that Ford was nominated, October 12, 1973, the U.S. Court of Appeals ruled that the tape recordings made by Nixon—which contained direct evidence of criminality and obstruction of justice by dozens of Administration officials including Nixon himself—must be surrendered to the Senate investigating committee.

Given the deep troubles of the President, it was considered a real possibility by the members of Congress that Nixon might resign his office to avoid prosecution, as Agnew had done. That possibility made it urgent that Ford—or someone with his

[12] See, for example, James Cannon, *Time and Chance: Gerald Ford's Appointment With History* (New York: Harper Collins Publishers, 1994), pp. 186-199.

capabilities—be confirmed as Vice-President: in the absence of a sitting Vice-President, the Speaker of the House would succeed to the White House.

Only the most partisan of the Congressional Democrats wanted Carl Albert, then the Speaker, to bear the burden of the Presidency; it was widely supposed that Albert's best years were well behind him. Nevertheless, nearly two months passed before Congress considered the nomination of Ford as Vice-President, so involved was that body over the question of Presidential misdeeds and with the consequences of Nixon's firing of Archibald Cox, the Special Prosecutor who demanded that the President surrender his collection of incriminating White House tape recordings.

On December 6, 1973, however, both houses of Congress confirmed the choice of Gerald Ford as Vice President by overwhelming margins. Quickly Ford was sworn into office.

Despite desperate efforts by the administration over the following months to slow or stop the prosecution of the Watergate affair, the Senate Select Committee inexorably demonstrated that Nixon himself was involved in a large-scale program that broke a variety of laws and had attempted to conceal the facts by misuse of the Internal Revenue Service, the Federal Bureau of Investigation, the Central Intelligence Agency, and the Department of Justice.[13]

At 9 am on August 8, 1974, President Nixon addressed the Nation via television to state his intention to resign his office during the next day. He became the first U.S. President to do so. He thus avoided protracted impeachment proceedings on criminal charges and abuse of his office. He also preserved his pension, his lifetime Secret Service protection, and other perquisites of the Presidency.

The next day, August 9th, Alexander Haig delivered Nixon's letter of resignation to Secretary of State Henry Kissinger, "I hereby resign the Office of President of the United States." At 12:03 pm, as Nixon and members of his family flew to California, Gerald Ford became President. Ford had some work to do.

Searching for an End to the Vietnam War

President Nixon had a little more luck in extricating the United States from the Vietnam War than had Lyndon Johnson. There was no way to "win" any more, only the possibility of withdrawing from the war-torn country without the stigma of losing. With Henry Kissinger, his foreign-policy guru, continually at his side, Nixon sought to capitalize on the gains in popularity that followed his visits to Russia and to Peking during the election year of 1972..

Once the elections were over, President Nixon ordered the heaviest bombardment ever—more than 36,000 tons of bombs dropped over a 12-day period in December—of the populous Hanoi-to-Haiphong corridor. The North Vietnamese asked for a return to peace negotiations.[14]

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[13] Ambrose, *Nixon, Volume Three,* p. 386.

[14] James MacGregor Burns, *The Crosswinds of Freedom* (New York: Random House, 1990), pp. 479-489.

Cease-fire talks early in 1973 gave the President the opportunity to promise "peace with honor," although the United States—despite pledges to its allies in South Vietnam—already had given in to the demand that North Vietnamese troops would remain in South Vietnam. Despite the talks, it proved necessary for the United States to continue routine bombing, not only in Vietnam but in Cambodia.

The Congress expressed its distaste for Nixon's style of governing with the War Powers Act, passed in August of 1973. This Act demanded that U.S. troops be brought home within sixty days unless Congress was consulted on military policy and agreed with the President's decisions.

The Vietnam War was winding down, not as a result of victory or defeat but of simple fatigue—the Nation was tired of sending its sons and daughters to participate in an expensive and unwinnable conflict on the other side of the world.[15]

In April 1975, under the anguished supervision of President Ford, the last U.S. civilians were evacuated from Saigon as the North Vietnamese took command of the beleaguered city.

Returning Vietnam veterans, frustrated and scarred in mind and body in battles that made no sense, added to the disaffection that ran through the country during this era.

Stagflation

As a believing Republican, President Nixon had a natural aversion to government economic controls. Nevertheless, in August 1971, he issued a 90-day freeze on wages, prices, and rents. Nixon took this distasteful step because of high (5 %) inflation, the Nation's first balance-of-payments deficit, and rising unemployment. He urged corporations to hold the line on stockholder dividends. For his part, he promised to reduce government expenditures and to reduce Federal employment by 5 %. As we mentioned at the beginning of this chapter and shall again later, NBS felt the full impact of these economies.

Nixon's efforts were sufficiently successful by the time of the 1972 elections that he could cite a rebounding economy as evidence that he should be re-elected. However, the rebound was brief, for the Nation's economic troubles were deep-seated.

The economic controls were continued, but gradually eased, during 1972 and 1973. They were abandoned in 1974, when the U.S. economic downturn became more pronounced. A condition of stagnant consumer demand accompanying relatively severe inflation became the definition of a new word—"stagflation."

The so-called New Economic Policy, announced by President Nixon during his first term, failed to curb the spending—in both the public and private sectors—that led to pronounced price inflation during 1973. In the meantime, U.S. industry, hard-hit by low-priced imported goods, languished. During 1973, U.S. automobile sales fell 11 million behind the 1972 figures. During 1974, unemployment reached 7.2 %, a 15-year high.[16]

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[15] James T. Patterson, *Grand Expectations* (New York: Oxford University Press, 1996), Ch. 24.

[16] Patterson, *Grand Expectations*, Ch. 25.

The House Committee on Science and Astronautics, inspired by Lewis Branscomb's vision of the Bureau of Standards, was seeking an expanded role and increased funding for NBS as one means to reverse the decline in U.S. technical productivity. At the same time, the House Committee on Appropriations, inspired by fears of profligacy, was seeking to reduce government expenditures. Could the Bureau staff not be nervous in this situation?

A Crisis in Energy

Shortages of energy, problematic for the United States since the mid-1960s, came into sharper focus during the presidency of Richard Nixon. Unhappily, energy woes had to share the attention of the Nixon administration with the Vietnam War and with the Watergate affair, which ripened and rotted during the same time interval.

For the most part, the energy crisis originated with the discovery of the "oil weapon" in the mid-East and in Libya.

In October of 1973, the Egyptians and the Israelis renewed their war, with the Egyptians gaining the early advantage via the time-honored technique of a surprise attack. The United States supplied Israel with enough ordnance to partially offset the early losses and create a stalemate. While the short Egypt-Israel war transpired, an oil cartel formed by the oil-exporting nations (the Oil Producing and Exporting Countries, or OPEC) decided unilaterally on an increase in the price of their product from $3 per barrel to $5, then to nearly $12. Overall, OPEC production was cut by 5 % per month; oil shipments to the United States from Libya were cut off entirely. Eventually the other OPEC nations joined the embargo to punish America for its assistance to Israel.

Almost immediately, gasoline and fuel-oil shortages and skyrocketing petroleum prices became a feature of the U.S. economic landscape.

The American standard of living had risen to a comfortable level in large measure because energy was available in abundance and at a low cost. The United States, with one-twentieth of the world's population, became responsible for a third of the world's energy consumption. And 30 % of U.S. oil use was made possible by foreign supplies in 1972. During the oil embargo, the American standard of living retreated somewhat. Energy costs contributed substantially to economic stagflation.[17]

The winter of 1973-1974 saw long lines of U.S. automobiles waiting for scarce gasoline from filling-station pumps. Many Americans wondered aloud why gasoline prices rose as strongly as they did, and whether price-gouging, rather than OPEC, was the real culprit. President Nixon, ordinarily opposed to controls by "big government," addressed the Nation with a call for conservation of energy.[18] Nixon asked his countrymen to respond to the shortage of oil by reducing consumption by 10-20 %. He suggested that occupants of homes, factories, offices, and stores lower the settings on their thermostats by several degrees. He advocated staggered working hours to take advantage of natural light and to avoid gasoline-wasting delays in traffic. And he urged

[17] Patterson, Ch. 25.

[18] *New York Times*, November 8, 1973, pp. 1, 33.

managers of utility companies to consider designing new power plants to burn U.S. coal rather than foreign oil. During his speech, the President also put forward "Project Independence," a program intended to permanently reduce the Nation's reliance on foreign oil. For a time, this initiative would involve several projects at the National Bureau of Standards.

By the end of 1973, the price of a barrel of oil rose to $11.65 by edict of OPEC. In only three months, this most common of energy sources had quadrupled in price; by the end of the decade, even this new price would triple.

NBS responded quickly to the president's request to conserve energy in homes. Working through the office of Virginia Knauer, the President's Special Assistant for Consumer Affairs, the Center for Building Technology produced two pamphlets as guides for saving energy in household heating (*Seven Ways to Save Energy in Household Heating*) and cooling (*Eleven Ways to Save Energy in Household Cooling*). Thousands of copies of the pamphlets were distributed nationwide by Knauer's office, and many of those were reproduced by private industry.

Science Loses Its Advocates[19]

In President Nixon's administration, admiration for the power of science warred with concern regarding scientists' never-ending demand for freedom and their continual need for money. Nixon demonstrated this ambiguity as he basked in the warm afterglow of achievements in the space program—culminating in the landing of Americans on the moon in 1969, 1971, and 1972— while gradually reducing support for the National Aeronautics and Space Administration as his need for economy in government spending became more acute.

The President's Science Advisory Council, the Office of Science and Technology, and the Presidential Science Advisor, monitoring the scientific and technological needs of the Nation since the days of Eisenhower, were consistently undercut by the Nixon administration. Ultimately they were discarded. Nixon's view was that the governmental science establishment should serve the constantly changing political needs of the administration. This view continually brought clashes with the scientists, whose logic was inevitably rooted in facts. A conscious program of eliminating positions altogether or replacing Kennedy-Johnson appointees with Republican loyalists went far towards producing the desired unanimity on science and technology issues.

The President periodically embraced crash programs in science that he thought could quickly solve technological problems—a view that perhaps had its origin in the success of the Manhattan project, which produced the atomic bomb and thereby quickly and decisively ended World War II. For example, in his first term, Nixon urged that large amounts of money be spent on the gasification of coal, on the fast breeder reactor, and in the pursuit of controlled nuclear fusion. Members of the scientific establishment,

[19] Much of the material in this section is derived from information given by James E. Katz, *Presidential Politics and Science Policy* (New York: Praeger Publishers, 1978) Ch. 9.

who had suggested no such list, were more than a little surprised at the presidential statement.

Toward the end of his first term, Nixon delivered to Congress a *Presidential Message on Science and Technology.* It contained a glowing endorsement of the scientific enterprise and an explicit reference to NBS as a key agency in the use of science for mankind. But it contained a caveat that advancements in science must be put to the service of civilian needs—the environment, health, energy, and transportation.[20] The President promised:

> To use the capabilities of our high technology agencies—the Atomic Energy Commission, the National Aeronautics and Space Administration, and the National Bureau of Standards—in applying research and development to domestic problems.

Nixon adopted a *National Technology Opportunities* program as one part of his announced plan. It ultimately involved NBS in an *Experimental Technological Incentives Program.* Remarkably, NBS suffered while it was being praised for its effectiveness. During Nixon's last years, the agency was asked to surrender 5 % of its full-time personnel, along with the funding to support them. The Bureau was also required to reduce the average grade level of its staff.

As the Watergate affair grew to dominate White House activities, Nixon's personal staff—particularly H. R. Haldeman and John Erlichman—took over more and more control of Nixon's appointment schedule. As one consequence of this change, even agency representatives charged with producing technical breakthroughs no longer could meet with the President to put forth their ideas.

PRESIDENT GERALD RUDOLPH FORD, JR.

President Gerald Ford, biological product of a failed marriage,[21] was the political product of a failed presidency. Born in Omaha, Nebraska, to an abusive father, Ford took Grand Rapids, Michigan for his hometown and he took the name of Gerald R. Ford, his kindly stepfather, as his own name. From his mother and his stepfather, Ford learned well the virtues of honesty and hard work. From his high-school and college experience, both in academics and in athletics, Ford learned the value of scholarship and competition. A child of the Great Depression, Ford also knew the value of a dollar.

By the time he was 32 years of age—at the end of World War II—Ford had graduated from the Yale school of law and had practiced his profession in Grand Rapids. He also had held positions as assistant football coach at Yale, professor of business law at Grand Rapids University, and lieutenant in the U.S. Navy with four years' service—two of those years as a deck officer on an aircraft carrier in the thick

[20] *The Public Papers of the President: Richard Nixon, 1972,* U.S.G.P.O., 1974, pp. 416-425.

[21] James Cannon, op. cit., Ch 1.

of some eleven Pacific battles of World War II. A standout among his colleagues for his honesty, judgment, and hard work, and for his capability to excel at any assigned duty, Ford was ready to become a front-line player in post-war America.

Ford won the first political campaign he ever entered: Congressman, Fifth District, Grand Rapids, Michigan, 1948. During his first term, he became friends with Representative Richard Nixon and won a spot on the House Appropriations Committee—one of the three most coveted assignments in the House. By the time that John F. Kennedy had defeated Richard Nixon in the Presidential campaign of 1960, Ford had been elected to his sixth term in Congress and was the ranking Republican on the Defense Subcommittee of the House Appropriations Committee. Ford, his wife, and their four children were citizens of Alexandria, Virginia, as well as of Grand Rapids.

When Richard Nixon won re-election as President in 1972, Ford was elected Minority Leader of the House of Representatives for the fifth time, capping a 12-term Congressional career. To his regret, Ford's career stopped short of his ultimate political goal: to become Speaker of the House. As luck would have it, the Republicans never gained control of the House after Ford reached the top of his party's Congressional delegation, so that the position of Speaker would forever elude him.

For a long time, Ford could not understand why the Watergate affair presented such a problem for his friend Richard Nixon. If the burglary was the work of Republican zealots, thought Ford, simply disavow them. If White House operatives were involved, seek them out, fire them, apologize for the unwarranted affront to civility, and go back to work. He could not believe that Nixon was personally involved—until the fact was obvious. Even in October 1973, when Nixon nominated Ford to replace Agnew as Vice President, Nixon gave no indication to his old friend that his career as President was even in jeopardy, let alone doomed.

Faced with a full field investigation (by 350 agents of the Federal Bureau of Investigation!) as a preliminary to Congressional confirmation as Vice President, Gerald Ford reacted characteristically. "Hold nothing back," he said to his staff. "Anything that they want, if we have it, give it to them. I don't want any papers from the files destroyed, or hidden, or doctored up. We are not going to cover up anything, and we are not going to stonewall."[22]

A Short Acquaintance

Gerald Ford became President in August 1974. With no executive experience in his background, he was thrust immediately into the most demanding of circumstances—completing the term of a resigned Chief Executive.

Ford saw his first responsibility to be the restoration of America's faith in its leader—in his case not an elected leader, but one chosen by the very man whose presidency he sought to redeem. A step in this direction was his nomination of Nelson Rockefeller, the experienced governor of the Nation's largest State, as Vice President. Much of America viewed Ford's pardon of Richard Nixon as a step in the opposite

[22] Cannon, op. cit., p. 229.

direction. Other steps— against inflation and underemployment, trade deficits, and the war in Asia—occupied his full attention for the balance of his term as President.

Barely 10 months after his inauguration, President Ford received a letter of resignation from Richard Roberts, Director of NBS. Given Ford's necessary preoccupation with more massive problems, it seems likely that he left the selection of a replacement for Roberts in the hands of Rogers C. B. Morton, appointed in May 1975 as his new Commerce Secretary, and Betsy Ancker-Johnson, who continued to hold the office of Assistant Secretary of Commerce for Science and Technology. Richard Roberts and Gerald Ford were destined for only a brief acquaintance.

RICHARD WILLIAM ROBERTS

Richard Roberts was born in Buffalo in 1935. He was educated as a physical chemist, receiving the undergraduate degree from the University of Rochester in 1956 and the doctorate from Brown University in 1959.

Although Roberts had spent the year following receipt of his doctorate as a National Research Council Postdoctoral Research Associate at NBS, he was not well-known to the Bureau staff in the way that Branscomb had been—instead, his career had been built at the General Electric Company (GE).

Roberts was less interested in laboratory science per se than he was in the management of science. Within 5 years of his arrival at GE, Roberts was appointed Manager of the Physical Chemistry Laboratory. In 1968, he was made Research and Development Manager of Materials Science and Engineering, a four-laboratory group of more than 250 technical people. At 33 years of age, he was directing GE work in artificial diamonds, in machining tools for special alloys, in new composite materials—including new types of magnets—and in coal gasification.

Not particularly active in politics but a registered Republican, Roberts' nomination as the seventh Bureau director could be perceived as trouble-free for the intensely partisan Nixon administration.

An interview with the new director was featured in a special edition of the NBS Standard.[23] In it, Roberts was asked about his immediate plans for the Bureau:

> In terms of detailed plans, the first thing I've got to do is really learn what's going on. I asked Larry Kushner to set up with the Institutes program reviews during the first week so I could get, in that time framework, an outline of everything that's going on.

Program reviews would become a way of life at NBS during the 30-odd months of Roberts' tenure.

Roberts quickly showed a lively interest in the public appearance of all aspects of the Bureau. Within 10 days of taking office, he had made suggestions for improving the appearance and readability of NBS publications such as the *Technical News*

[23] "Roberts Takes NBS Reins," *NBS Standard,* Special Edition, February 1973, 4 pp.

Richard W. Roberts was the seventh director of NBS. Trained as a chemist, his chief interest was in technical management.

On November 27, 1973, First Lady Patricia Nixon came to Gaithersburg to view a townhouse equipped with solar panels under an agreement between NBS and the Department of Housing and Urban Development. Mrs. Nixon and NBS Director Richard W. Roberts were photographed while fielding questions from reporters.

Bulletin, he had requested that a presentation package be prepared for his own use with perhaps 80 color slides, he had requested that Kushner prepare a set of management seminars, and he had requested that his speeches be printed in "an attractive format" for distribution to the public.[24]

Old Bureau hands who worked closely with Roberts agree on several of his personality traits.[25] He was personally ambitious. He was driven to seek perfection, especially in the area of presenting descriptions of technical work, an area closely related to public relations. He came to work early and left late, and he expected those around him to do the same. He was demanding in his judgments of the quality of presentations, often finding flaws that no one else noticed. He was extremely sensitive to the impact on its "customers" of work done at NBS; he probed quickly and with vigor to determine the extent to which Bureau managers were familiar with their "client base." And he was preoccupied with making management "cost effective," a term that had a less precise meaning in government agencies than it did in the private sector.

Richard Roberts' leadership at NBS was recognized by the Downtown Jaycees of the District of Columbia when they presented the Arthur S. Flemming Award to him on February 27, 1975. The award, given to outstanding young Federal employees, had been given to 13 Bureau scientists since its establishment in 1948. Roberts was the first NBS staff member to win the award strictly for administrative work.[26]

A New Management Style

Roberts' predilection for communication with his constituency found ample room for exercise at NBS. Despite the fact that his predecessor, Lewis Branscomb, had pushed mightily in the same direction, there had not been time enough during Branscomb's short tenure to move the Bureau very far from its accustomed posture as a quiet purveyor of facts.

The new director took up his task with a will. His efforts to impose a new, higher-visibility management style on NBS appeared in the form of new and modified organizational entities, new leaders, intense reviews of Bureau programs, and a public face for NBS intended to convey a fuller appreciation of a capable agency.

[24] Note to W. Reeves Tilley, February 7, 1953, RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to W. E. Small, February 12, 1953, RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to L. M. Kushner, February 12, 1953, RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to W. E. Small, February 12, 1953, "NBS Publication Covers"; RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to W. E. Small, February 15, 1953; RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973.

[25] Howard E. Sorrows, Oral History, December 10, 1986. See also Ernest Ambler, Oral History, November 7, 1986. See also Arthur O. McCoubrey, Oral History, November 3, 1986.

[26] *NBS Standard,* Vol 20, No. 6, March 12, 1975, p. 3.

On December 5, 1973, noted anthropologist Margaret Mead gave a talk entitled "Women—Oppressed and Unoppressed" in the NBS/Gaithersburg Red Auditorium. Mead was invited by the Standards Committee for Women to be the keynote speaker for the NBS observance of the Department of Commerce Federal Women's Program Week. In this photograph, Mead chatted with NBS Director Richard W. Roberts.

NBS Holds an Open House

Consistent with his desire for greater publicity and public awareness of the Bureau and its activities, Roberts scheduled an open house for October 26-27, 1973.

It was scarcely the norm for NBS to open its doors to the general public on the spur of the moment. Even during the 50th anniversary of the Bureau's founding in March 1951, visits to its laboratories were limited mainly to attendees of a large variety of celebratory scientific and technical symposia.[27]

The Roberts open house had a simpler objective than the "golden anniversary" in 1951: to advertise a major scientific laboratory to those who might not have been aware of its existence. A front-page article in the employee newsletter outlined plans for the event, which included some 118 tour stops at which Bureau staff members would explain their work.[28]

More than 20,000 students and other visitors crowded the grounds on Friday, October 26, many escorted by young tour guides who were the children of staff members. On Saturday, October 27, another 15,000 interested visitors came to NBS to see the types of projects that the Bureau supported.[29]

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[27] Annual Report, 1951, p. 100. See also *Technical News Bulletin*, 1951 and 1952.

[28] "NBS Open House," *NBS Standard*, Vol. XVIII, No. 15, October 24, 1973, pp. 1-5, 8. See also NBS Admin. Bull. 73-67, October 18, 1973.

[29] "Dick Roberts Reviews the Open House," *NBS Standard*, Vol. XVIII, No. 16, pp. 2, 3, 7, 8.

The open house was judged to have been successful both in getting more publicity for NBS and in communicating to the public a better idea of the highly technical, yet often down-to-earth projects accomplished on a daily basis by Bureau staff members. It also served as a warm-up session for a larger celebration planned for 1976—the Nation's bicentennial and the Bureau's 75th anniversary.

Programmatic Center for Consumer Product Safety

Director Roberts continued Lewis Branscomb's efforts to create program management in consumer-related areas—both for better Bureau visibility and for better coordination with industry groups. During his first month on the job, Roberts formed a Programmatic Center for Consumer Product Safety.[30] This step consolidated in the Institute for Applied Technology oversight of all work in the Consumer Product Systems Section of the Measurement Engineering Division, the Product Flammability Section of the Fire Technology Division, and the Consumer Product Activities group of the Technical Analysis Division.[31]

Jacob Rabinow and Melvin R. Meyerson were appointed Director of the new Center and Associate Director for Consumer Activities, respectively. Their duties lay in coordinating NBS work in the participating sections with the new Consumer Product Safety Commission, headed by Lawrence M. Kushner, former NBS Deputy Director. As with most NBS programmatic centers, responsibility for funds, personnel actions, space, and equipment remained with the parent divisions of the participating sections.

On December 8, 1974, the name of the unit became "Center for Consumer Product Technology" and it became a line organization of NBS. Assigned to the new center as staff members were the Office of Consumer Product Safety under Walter G. Leight, the Law Enforcement Standards Laboratory headed by Jacob J. Diamond, the Product Systems Analysis Division led by Melvin R. Meyerson, and the Product Engineering Division, managed by G. Franklin Montgomery. No Center Director was chosen immediately; Marshall Isler was designated Acting Deputy Director.[32] Stanley I. Warshaw was later recruited from the American Standard Company as director of the Center.

More Change for NBS Programs

During his short tenure, Director Roberts continually modified the Bureau program structure. Among the changes were the following:

- Executive Board re-structured, March 1973. Roberts assembled a new membership roster and set up a new meeting format and schedule.

[30] NBS Admin. Bull. 73-11, February 15, 1973, "Programmatic Center for Consumer Product Safety Established."

[31] A subsequent NBS Admin. Bull. 73-40, June 20, 1973, assigned to the Center the coordination of all NBS work undertaken on behalf of the Consumer Product Safety Commission.

[32] NBS Admin. Bull. 74-81, December 30, 1974.

- Oversight of interagency collaboration, May 1973. A new NBS-Other Agency Board of Coordinators was established. Roberts charged the board with promoting and monitoring interagency programs.

- Oversight of energy programs, July 1973. David A. Didion, program analyst for the Institute for Applied Technology, was given the additional responsibility of generating and monitoring programs in the area of energy utilization and conservation.

- Office of Air and Water Measurement, December 1974. This office supplanted the former Measures for Air Quality and expanded its horizon. James R. McNesby continued to lead the newly expanded office.

- Office of Energy-Related Inventions (OERI), March 1975. In order to augment the Bureau's energy-conservation effort, Roberts established the OERI within the Institute for Applied Technology. It was formed to seek and screen energy-related inventions. George P. Lewett, formerly a staff member in the Technical Analysis Division, was designated Acting Chief of the office.

One of the first evaluators of energy-related inventions for OERI was, surprisingly, Jacob Rabinow. Rabinow retired from the Bureau just as OERI was created, but was enticed to return as a "rehired annuitant" to lead the evaluation team.

A New Management Team

Director Roberts made several changes in the senior management of the Bureau, including some that were mentioned in the preceding section. In most cases, new appointments came from within NBS ranks; in others, new managers were introduced to the Bureau:

- Ernest Ambler named NBS Deputy Director, June 1973. One of Roberts' first duties—though not one that he had expected—was to replace Lawrence M. Kushner as his deputy. Roberts had expected Kushner to stay on.[33] The latter's long experience with the Bureau and with external organizations such as the U.S. Congress could have eased the transition from industrial manager to Federal manager for the new director.

As senior members in the Nixon administration realized that Roberts would become NBS Director, Kushner was offered the position of Commissioner in the brand-new Consumer Product Safety Commission (CPSC), mandated by Congress in October 1972.[34] Richard O. Simpson, Deputy Assistant Secretary of Commerce for Product Standards, was appointed Chair of CPSC. The nascent organization especially wanted to name a Commissioner who was familiar with the evolution of product standards.

[33] "Roberts Takes NBS Reins," Special Edition, *NBS Standard,* February 1973, p. 1.

[34] Consumer Product Safety Act, Public Law 92-573, October 27, 1972.

Kushner had considerable experience in that area, and he accepted the offer of the new position.[35] Other commissioners included Constance B. Newman, Director of Volunteers In Service to America; Barbara Franklin, an expert on legislative politics; and David Pittle, a safety-minded engineer from Carnegie-Mellon University.

By May 1973, Kushner had left the Bureau. When Kushner departed, Roberts spent less than one month studying his subordinates in a search for a new deputy. He quickly chose Ernest Ambler, then Director of the Institute for Basic Standards (IBS). The appointment was made effective on June 11, 1973.[36] Roberts appointed David T. Goldman, Ambler's deputy, as Acting Director of IBS.

- Jordan Lewis to head the Experimental Technology Incentives Program (ETIP). By mid-1973, the funding level for ETIP was settled and a search was under way for a suitable manager for the new program. Roberts chose Jordan D. Lewis, former Director of Applied Technology Programs at the Battelle Memorial Institute in Columbus, Ohio.[37] Lewis had considerable experience in developing technologies in the areas of new products and processes.

- John Lyons to head the NBS Fire Program. At the behest of Karl Willenbrock, Director of the Institute for Applied Technology, John Lyons, an expert on certain features of fire research at the Monsanto Chemical Company, was brought to NBS in October 1973 to head the Bureau's fire program.[38] Lyons had been somewhat critical of the fragmented NBS program in fire research and safety, and it was hoped that he could bring a better focus to the work.[39]

In May 1974, a Programmatic Center for Fire Research (PCFR) was established to perform planning, coordination, and review of all Bureau work on destructive fires. Reporting to Lyons, the new Director of the PCFR, were an Associate Director for Fire Science and Information and an Associate Director for Fire Technology. Robert S. Levine was brought from NASA to fill the former position; Irwin A. Benjamin, chief of the Bureau's Fire Technology Division, was named to the latter post.

To facilitate the changes, the Fire Technology Division was reorganized into two branches, the Fire Science and Information Branch and the Fire Technology Branch. The former division administration retained responsibility for funds, personnel, equipment, and other resources.[40]

In 1974, the Department of Commerce, following the dictate of the Federal Fire Prevention and Control Act, mandated the creation at NBS of a Center for Fire Research.[41] The Bureau soon complied with the act, establishing the center with Lyons

[35] L. M. Kushner, Oral History, June 7, 1988.

[36] NBS Admin. Bull. 73-37, June 11, 1973.

[37] NBS Admin. Bull. 73-62, September 27, 1973.

[38] NBS Admin. Bull. 73-70, October 29, 1973.

[39] John W. Lyons, Oral History, June 1, 1993.

[40] NBS Admin. Bull. 74-39, May 17, 1974.

[41] The originating directive was DOO 30-2B dated April 28, 1975.

as Director, Levine as Chief of the Fire Science Division, and Benjamin as Chief of the Fire Safety Engineering Division.[42]

- Arthur O. McCoubrey to head the Institute for Basic Standards (IBS). Roberts selected Arthur O. McCoubrey, former Vice-President and Director of Frequency and Time Systems, Inc., as Director of IBS effective March 18, 1974. He succeeded David T. Goldman, Acting Director.

  As with other appointments from outside NBS, McCoubrey brought a wealth of understanding of the private sector to the Bureau's senior management. McCoubrey also had considerable experience in research in atomic time and frequency standards, both at Frequency and Time Systems and at Varian Associates.[43]

- Retirements. Several members of Roberts' management team retired during his tenure. Among these was Robert S. Walleigh, Associate Director for Administration under Astin, Branscomb, and Roberts; he had joined NBS in 1943. Roberts recruited Richard P. Bartlett, Jr., a former administrator in the Department of Agriculture, to succeed Walleigh.

  Another senior retiree was George R. Porter, chief of the Personnel Division for nearly a quarter-century. Mati Tammaru was named as his successor.

  Clarence N. Coates, Assistant to the Director for Congressional Relations and an NBS employee for twenty years, also retired. He was succeeded by Esther C. Cassidy, formerly a physicist in both the Heat Division and the Electricity Division and an expert in high-voltage measurements.

A New Secretary of Commerce

In February 1975, President Ford asked Frederick B. Dent to become his Special Representative for Trade Negotiations, a post that would bring Dent into the General Agreement on Tariffs and Trade.[44] Dent thus completed two years as Secretary of Commerce, during which he served and defended President Nixon with great vigor. Dent also was credited with inducing U.S. industry to pursue a policy of energy conservation.

Ford acted quickly to replace Dent, nominating Rogers C. B. Morton—Secretary of the Interior since 1971—for the Commerce post on March 27, 1975. Morton had served the State of Maryland in the House of Representatives from 1962-71, where

[42] NBS Admin. Bull. 75-26, June 11, 1975.

[43] A. O. McCoubrey, Oral History, November 3, 1986.

[44] Edwin L. Dale, Jr., "President Names Dent Top Trade Negotiator," *New York Times*, February 28, 1975, p. 43.

NBS Congressional Liaison Esther Cassidy and NBS Director Richard W. Roberts spoke with Senator Claiborne Pell of Rhode Island (right) and a member of his staff, Bill Young (left), on the steps of the Gaithersburg Administration Building. Pell spoke at a Metric Education Conference held at the Bureau in May 1975.

In November 1974, members of the National Bureau of Standards (NBS) Executive Board posed for a photograph on the spiral staircase in the NBS/Gaithersburg library. From right to left were Arthur O. McCoubrey, Robert S. Walleigh, Ruth M. Davis, F. Karl Willenbrock, Richard W. Roberts, Ernest Ambler, Howard E. Sorrows, John D. Hoffman, and Edward L. Brady.

he had become a close friend of then-Congressman Ford. In an article describing the appointment, New York Times reporter B. A. Franklin stated:

> The move will also place Mr. Morton in a position where he could begin organizing the financial base for Mr. Ford's announced 1976 election campaign, a function for which the top Commerce post has long served.[45]

[45] Ben A. Franklin, "Morton, in a Cabinet Shift, Picked for Commerce Job," *New York Times*, March 28, 1975, p. 1.

Sure enough, Morton left his Commerce post in January 1976 to become White House counselor on economic and domestic policy matters, in close liaison with the chairman of Ford's Re-Election Campaign Committee.[46]

Betsy Ancker-Johnson, who had replaced Richard O. Simpson as Assistant Secretary of Commerce for Science and Technology (to whom the Director of the Bureau reported) in mid-1973, continued to occupy that position until the beginning of the Carter Administration in 1977.

Roberts Departs for the Energy Research and Development Administration

Despite his considerable abilities in the management of technical work and in the persuasive presentation of its results, several of his senior Bureau aides recall that Roberts never felt quite at home at NBS.[47] The preoccupation of many of its staff with extreme detail and meticulous care did not resemble the type of work that fitted his experience in an industrial laboratory. He also lacked experience with federal research and development and contact with public policy in science and technology. He found, he said, that NBS was not "his cup of tea." After a couple of years as director, Roberts developed the view that he could better realize his personal goals by becoming involved in the Nation's nuclear energy program.

On June 10, 1975, Director Roberts sent a letter to President Gerald Ford resigning from his office. In his letter of resignation, Roberts alluded to the many contributions of NBS to America's scientific and technical life, as well as to the increasingly central role that energy seemed destined to play in the country's progress. Roberts emphasized the importance of energy as "the major technical problem facing the nation in the years ahead." He further specified nuclear energy as offering "great potential," and "a great individual challenge in helping fulfill that potential."

As his principal reason for leaving NBS, Roberts stated his intention to accept a pending nomination to the post of Assistant Administrator for Nuclear Energy in the newly formed Energy Research and Development Administration. Roberts asked that his resignation become effective upon his confirmation in his new position.[48]

The Energy Research and Development Administration (ERDA) was created to focus the administration's energy-conservation efforts. Prior to the formation of ERDA, responsibility for energy programs was fragmented among several Executive-branch agencies, including the Atomic Energy Commission, the Federal Power Commission, and the National Science Foundation. Public Law 93-438, signed by President Ford on

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[46] *New York Times*, January 14, 1976.

[47] See Oral Histories conducted by Karma Beal to compare the management styles of Branscomb, Roberts, and Ambler: Arthur O. McCoubrey, November 3, 1986; Robert S. Walleigh, November 5, 1986; F. Karl Willenbrock, November 7, 1986; Ernest Ambler, November 7, 1986; Edward L. Brady, November 10, 1986; and Howard E. Sorrows, December 10, 1986.

[48] Letter, RWR to President Gerald Ford, June 10, 1975, RHA; RG 167; Director's Office; Box 283; Folder RWR Chron; June 1- June 30, 1975.

October 11, 1974, dissolved the AEC, replacing it with the Nuclear Regulatory Agency and ERDA. Robert C. Seamans, Jr., former Secretary of the Air Force, was the first and only Administrator of ERDA—the agency was replaced by the Cabinet-level Department of Energy on October 1, 1977. President Jimmy Carter named James R. Schlesinger to the post of Secretary of Energy.

A week after receiving Roberts' letter of resignation, President Ford responded with abundant praise for his leadership in organizational development and program planning at NBS. Ford accepted the resignation on Roberts' terms. Roberts left his Bureau post on June 28, 1975.

Coincidentally, June 10, 1975 was not only the date of Roberts' resignation from the Bureau directorship; it also marked the beginning of the two-day formal Visiting Committee meeting at NBS. Although no inkling of his departure had been given to the committee, Richard Roberts greeted them with the announcement that on that very day he had tendered to President Ford his resignation as NBS Director.[49]

After Roberts' departure, a message from him to the NBS staff was published in the Bureau's employee bulletin issued July 16, 1975:[50]

> On June 30, 1975, I was sworn in as Assistant Administrator for Nuclear Energy in the Energy Research and Development Administration. This new assignment involves one of the most challenging technical problems facing the Nation—that of providing abundant energy for the years ahead.
> NBS is unique in mission, reputation, and quality of staff. The work done here is important to science, commerce, industry, government, in fact to all Americans. My leaving the Bureau does not mean an end to my interactions with you. ERDA, like all technical institutions, relies heavily on NBS output.

Like Seamans, Roberts remained at ERDA until its demise in 1977. Then he returned to the General Electric Corporation as a member of the Corporate Technology staff.

For the second time in succession, a newly appointed director of the Bureau had failed to reach his third anniversary. Five men had led NBS through its first 68 years; now two were gone in the space of another six years, leaving the staff to wonder whether change at the top was to become the new norm.

On June 30, 1975, Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology, designated Ernest Ambler as Acting Director of NBS on behalf of President Ford and Secretary of Commerce Morton. Robert Walleigh, only a few months retired from his long-time position as Associate Director for Administration, was coaxed by Ambler to return to NBS as Acting Deputy Director.[51]

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[49] Transmittal letter of Visiting Committee verbal report to the Secretary of Commerce, RWR to Arthur M. Bueche, Committee Chair, June 18, 1975, RHA; RG 167; Director's Office; Box 283; Folder RWR Chron; June 1- June 30, 1975.

[50] *NBS Standard,* Vol 20, No. 15, July 16, 1975, p. 2.

[51] Oral History, Robert S. Walleigh, November 5, 1986.

Roberts' Impact on NBS

Ernest Ambler, Roberts' successor as Director of NBS, recalled three features of his predecessor's leadership as having been especially useful to NBS in the increasingly political environment in which it operated.[52]

First, Roberts demanded from the Bureau staff a high level of "readability" for all management-level presentations—use of many colorful slides, persuasive references to user communities and minimization of arcane or tedious technical details. Adoption of a showy style to present topics that were really technical in nature engendered time, effort and—in the case of many old-time Bureau hands—grumbling, but Ambler was convinced that technical presentations became more effective as a result of the change.

A second Roberts initiative was to combine the NBS Program Office, the Budget Office, and the Accounting Division into a new unit known as the Office of Programs, Budget and Finance. Ambler himself was responsible for carrying out this change, which he felt provided much-needed streamlining of the Bureau's project administration.

The third significant feature of Roberts' leadership in Ambler's view was the elevation in importance of close liaison between NBS and Congress. Early in 1975 Roberts brought Esther Cassidy, an experienced scientist in the area of high-voltage measurements, to his staff as Assistant to the Director for Congressional Liaison. Among other activities, her responsibility was to ensure that Bureau programs were well understood by members of Congress and their staffs. Ambler stated:

> This last activity contributed to Congress holding 1977 Authorization Hearings,[53] the first held since 1971. This ended their reliance on a 'continuing authorization' and began regular annual authorization hearings starting in 1979 with a so-called 'field hearing' in the Red Auditorium at NBS with (Congressmen) George Brown and Don Fuqua attending.

An early consequence of Roberts' desire for improved presentation skills by NBS managers was the initiation of regular reviews of Division programs. These took on the appearance of "screen tests," with as much emphasis on style as on content. They were held in the Bureau's Green Auditorium with the Program Office staff and all NBS line managers down to section chiefs in attendance. As the ground rules became clearer, the presentations became more polished, occasionally with two projectors of color slides in operation at once. As was true in any organization, better performance in the reviews meant a happier life for managers at NBS.

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[52] Ernest Ambler, "Historical Perspective: 1973-1988" in *NBS/NIST A Historical Perspective, A Symposium in celebration of NIST's Ninetieth Anniversary, March 4, 1991*, NIST Special Publication 825, April 1992, pp. 31-42.

[53] The reader should recall that Authorization Hearings led to *permission* or to a *mandate* for Bureau activities, whereas Appropriation Hearings (see A Program in Technology Incentives later in this chapter) led to *funding* (or lack of funding) for them.

There is no doubt that Roberts wholeheartedly endorsed the energy-conservation, environmental-protection, and other consumer-oriented goals of the Nixon administration. One of his first actions as director was to change its scientifically oriented *Technical News Bulletin* into a popular-science format. Whereas the *Technical News Bulletin* was of interest mainly to scientific and technical workers in industry, government, and academia, its replacement, entitled *Dimensions/NBS,* was slanted towards the "man-in-the-street." In a leadoff announcement of the change, Roberts wrote:

> Since its founding at the turn of the century, the National Bureau of Standards has communicated the results of its work to the public. Initially, that public was largely the academic, scientific, engineering, and technical communities, and they are still in the forefront.
>
> In the last decades, however, a new pattern emerged. As the Bureau became more directly involved in immediate national problems and goals, its work also began to interest additional, broader audiences.
>
> At present our audience includes not only practitioners of the professional disciplines but also—very literally—the people who live down the block: the consumer, the student, the housewife, the homeowner.[54]

Roberts' view of the NBS constituency colored his whole approach to the Bureau's work. His efforts accelerated changes in the composition of its workforce and its mission that eventually would remake the National Bureau of Standards.

TECHNICAL WORK OF THE BUREAU, 1972-75

Despite the growing trend that eventually would take many of the Bureau's resources away from basic studies in physics and chemistry—and from fundamental standards work, too—most of the NBS technical work followed well-worn paths during the directorship of Richard Roberts. Projects attacking the energy crisis, environmental concerns, and public safety perhaps were better identified and more publicized than they might have been in earlier years, but a major swing in the Bureau's direction would have been hard to document.

As was the case in previous chapters, we offer in the following pages a few examples—chosen from a multitude of projects in dozens of laboratories—that provide glimpses into the minds of NBS scientists and evidence of the status quo in a unique institution.

A Program in Technology Incentives

The *Experimental Technology Incentives Program* (ETIP), created in concept during the directorship of Lewis Branscomb, began to produce results under Richard Roberts. The charter for the project was recorded in the House Appropriation hearings for Fiscal 1973:[55]

[54] R. W. Roberts, "to our readers," *Dimensions/NBS,* p. 179, August 1973.

[55] House Hearings for Fiscal 1973 (March 28, 1972) pp. 1085-1086.

> In partnership with the private sector, NBS will test the usefulness of various mechanisms and incentives to stimulate the generation and application of private research and development in ways that permit the private sector to further the Nation's productive capacity, industrial competitiveness, and our national well-being. The end product of this program is a better understanding of these mechanisms and incentives.

In creating ETIP, the Administration—mimicking successful foreign competitors—was seeking ways to make U.S. industry more effective in an effort to improve a dismal economy. It was not the usual type of request made of the Bureau, but a worthy goal nonetheless.

As noted earlier, Jordan D. Lewis, late of the Battelle Memorial Institute in Columbus, Ohio, where he headed applied technology programs, was selected by Richard Roberts to lead ETIP.[56] Lewis named Richard T. Penn, on the staff of the Institute for Applied Technology since coming to the Bureau in 1970, as his deputy for operations.

In concept, ETIP was similar to a project lodged in the National Science Foundation, called the *Experimental Research and Development Incentives Program.* Although a merging of the two efforts was considered during the planning stages, they remained separate because of the differing types of activity involved.

The ETIP experiments initially involved four program areas: procurement, regulation, civilian research and development, and small business.

In the procurement area, headed by Ralph Bara and Joseph G. Berke, a variety of ideas were tested by which the Federal Government, a mammoth customer for technical products, could pull U.S. industry towards innovation. Among the ideas were the use of performance specifications rather than design specifications as a means to spur innovative solutions to problems such as unwanted noise in appliances. As an example of this idea, the General Services Administration in 1974 advertised for bids on 10,000 lawn mowers with the proviso that they radiate 50 % less acoustic noise than the then-current average for that type of tool.[57] Later, NBS cooperated with the Consumer Product Safety Commission by measuring sound levels endured by operators of small, motorized lawnmowers.

The GSA bid also illustrated the principle of prototype purchasing, in which the government could acquire promising new products not yet on the market. Other procurement features included the use of multi-year procurement, value incentives, and cost contracting.

In the regulation area, four state public-utility commissions were selected for experiments applying computerized data and analysis techniques to improve utility rate-setting processes and regulatory practices. Philip J. Harter, chief of the ETIP regulatory programs, provided details of the experiments in an article in *Dimensions/NBS.*[58] It

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[56] "New ETIP Director at NBS," *Dimensions/NBS,* Vol 57, October 1973, p. 249.

[57] "ETIP on the move," *NBS Standard,* April 24, 1974, pp. 4-5.

[58] "ETIP, Utility Commissions and Policy Experiments," *Dimensions/NBS,* Vol. 59, May 1975, p. 112.

In a project undertaken with the Consumer Product Safety Commission, Jonathan Adler of the NBS Sound Section measured the sound level and thus the hearing-damage potential of a power lawnmower. The sound of the mower was picked up by microphone just below his right ear.

was hoped that elimination of delay and uncertainty among regulators would remove barriers to technological innovation.

In a third area, headed by James Kottenstette and Gregory C. Tassey, Federally sponsored research and development was used in an attempt to create new products for sale to the general public. In one experiment, the government issued a request that industry provide non-flammable cotton-polyester fabric. In response to the request, a group of yarn and textile manufacturers, university scientists, chemical companies, and other technical organizations formed a consortium to bring such a fabric to market.

In a fourth area, the impacts of regulatory compliance and the dearth of venture capital on innovation by small business were examined.

The ETIP experiments continued until 1977.[59] Evaluating the success of the program was not an easy task, inasmuch as the efficiency of whole industries was involved. But it was gratifying to NBS management to see the trust in the ingenuity of the Bureau that was implied by the request that NBS undertake the project. ETIP did not involve physical or chemical measurements or standards, or any of the other usual activities of NBS—only its capability for problem-solving.

[59] See "Evaluative Reports on the Experimental Technology Incentives Program for 1975, 1976, and 1977," National Academy of Sciences.

The Bureau Gets a New Fire Law and a New Fire Center[60]

America Burning

On May 14, 1973, the National Commission on Fire Prevention and Control issued a report entitled *America Burning*. The report had been mandated in the *Fire Research and Safety Act of 1968.*

America Burning was a powerful indictment of America's fire safety record. Among the major industrial nations of the world, the United States had the highest per capita death and property-loss rate caused by fire. In 1973, fires killed 12,000 people and injured 300,000. Of these, 50,000 were hospitalized for extended periods. The total economic cost of fire was estimated at $11 billion for that year.

Ninety recommendations intended to reduce by 50 % the level of American fire losses were included in the report: among these were suggestions that NBS and the National Science Foundation collaborate in sponsoring research on fire prevention, fire-fighting, and fire-service needs; that NBS and the National Institutes of Health collaborate in developing standards for combustion toxicology; and that NBS develop guidelines for a systems approach to fire safety.

The awful numbers in the Commission report immediately triggered new action in the Congress. Among some 173 pieces of legislation introduced in the 93rd Congress was a bill entitled *Fire Prevention and Control Act of 1973*. It was introduced jointly by Senator Warren Magnuson and Representative Wright Patman.[61] Utilizing many of the suggestions made by John Rockett and Alex Robertson of the NBS Fire Research and Safety Office, the committees crafted a new law, the *Federal Fire Prevention and Control Act of 1974,* Public Law PL93-498, 88 Stat. 1535-1549, enacted on October 29, 1974.

Federal Fire Prevention and Control Act of 1974

The new act called for the creation within the Department of Commerce of a National Fire Prevention and Control Administration (NFPCA) with the primary responsibility for public education on fire and for developing the "technology" of fire-fighting—equipment and equipment standards for compatibility. The NFPCA was to be directed by an Administrator whose duties would include supervising a National Academy of Fire Prevention and Control and a National Fire Data Center, as well as providing assistance to state and local fire programs.

The Academy was created to develop and offer training to state fire officials and to assist in developing training-certification criteria. The Data Center was to "gather, analyze, publish, and disseminate information related to the prevention, occurrence, control, and results of fires of all types."

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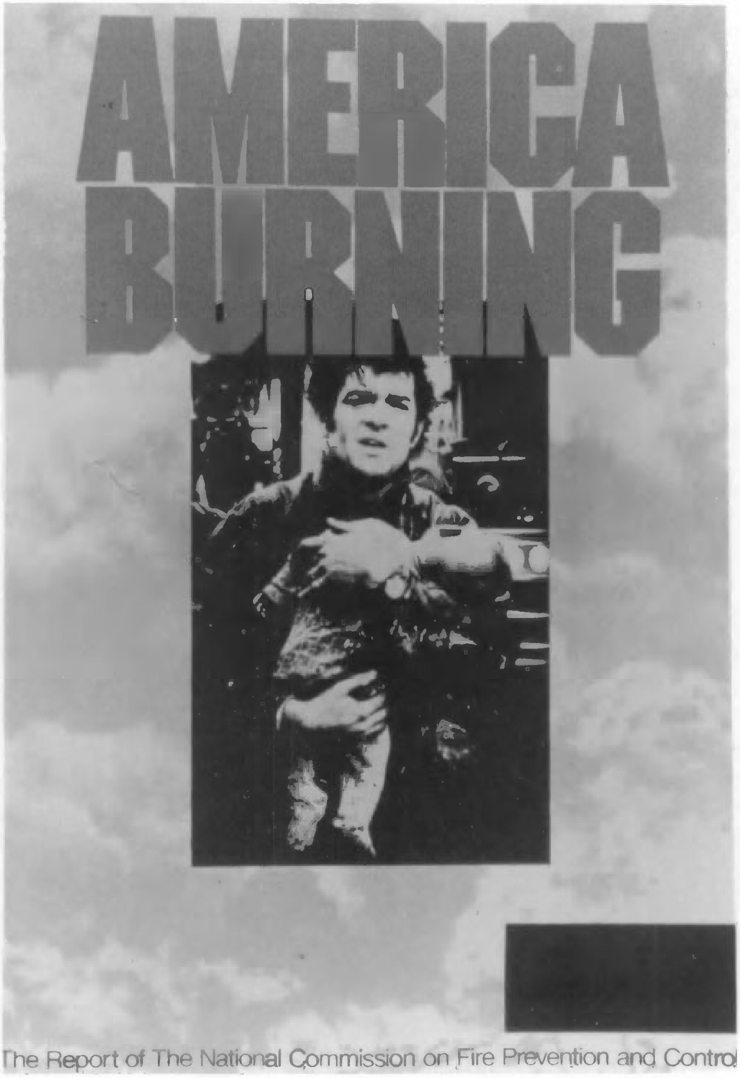
[60] Much of this material came from an excellent summary written by Daniel Gross; "Fire Research at NBS: The First 75 Years," an invited lecture at the *Third International Symposium on Fire Safety Science,* 1989, pp. 119-133.

[61] House hearings, FY 1975, p. 843, pp. 838 ff, April 9, 1974.



America Burning: The Report of The National Commission on Fire Prevention and Control (1973). The report contained fire statistics that showed the United States had one of the highest per-capita fire-loss rates in the world.

Center for Fire Research

One of the provisions of the Fire Prevention Act of 1974 established at NBS a Center for Fire Research (CFR), "To conduct basic and applied fire research, research into the factors influencing human victims of fire, and operation tests, demonstration projects, and fire investigations." The CFR would act independently of the NFPCA, but would consult with the Administration to assure that the two programs continued to be complementary. The Center was to be funded as a separate line item in the Bureau's budget, with support at the level of $3.5 million for Fiscal year 1975 and $4 million for Fiscal year 1976.

The Bureau's Center for Fire Research was finally to become a full-fledged, highly focused operation that would include an integrated research program as well as a University-grants-and-contracts collaboration with the National Science Foundation. As noted earlier, John W. Lyons, recently hired from the Monsanto Corporation to direct the NBS fire effort, became Director of the new organization.

The overall plan of PL93-498 offered a wide-ranging and useful effort, centered in the Department of Commerce, to reduce America's scandalous fire losses. Total Commerce budget requests for Fiscal years 1975 to 1977 were expected to amount to $6 million, $8 million, and $10 million, respectively, with the share for projects in the NBS Center for Fire Research scheduled for $2 million, $3 million, and $3.3 million.[62]

Shortly after enacting the Federal Fire Prevention and Control Act, the Congress decided to mandate the transfer of a set of fire-research grants from the National Science Foundation (NSF) to NBS. The program, funded at about $2 million per year, was part of NSF's *Research Applied to National Needs* activity. It supported a spectrum of fire-research studies at several universities and non-profit institutions. This assignment provided a valuable addition to the Bureau fire program, giving it direct access, either in-house or by contract, to much of the world's most advanced fire research.

Center Director Lyons took positive steps to ensure that the job of monitoring outside contracts would become a benefit to NBS fire research, not a detriment. Each grant was assigned to one or another of the Center's research groups, and the work of the grant was reviewed along with the in-house work of the group. That approach worked well—in later years, Lyons considered that the Center for Fire Research (CFR) experience was instructive in preparing NIST personnel for similar contract monitoring when he became Director. In addition, a number of future CFR employees became acquainted with the Bureau through the program.

At the request of NBS Director Ambler, Lyons and his senior staff prepared a detailed document, which they titled *Reducing the Nation's Fire Losses—The Research Plan,* that presented CFR proposals to fulfill the manifold requirements of the 1974 fire act. Ambler was pleased with the plan and circulated it both within and outside NBS.[63]

Law Enforcement Steps Forward at NBS

Work on law enforcement standards began at the Bureau shortly after President Johnson's Commission on Law Enforcement and Administration of Justice wrote a stirring call for safer streets.[64] The 90th Congress responded with the *Omnibus Crime*

[62] Senate hearings for FY 1977, p. 583.

[63] John W. Lyons kindly supplied the information on which much of the foregoing material was based.

[64] *The Challenge of Crime in a Free Society,* 1967.

Control and Safe Streets Act of 1968,[65] which created the Law Enforcement Assistance Administration (LEAA). The LEAA quickly turned to NBS for help in formulating standards that would be useful to state and local police organizations across the United States. Staff members of the Technical Analysis Division responded with new projects on computer-aided courtroom reporting and on the use of television in courtrooms to "get the ball rolling." Then in January 1971 the Bureau's Law Enforcement Standards Laboratory (LESL) became a reality.

Within four years of its founding, LESL had completed more than 45 projects and was pursuing twice that many for three outside sponsors. LESL performed three main types of activities: laboratory testing of equipment; development of equipment performance standards and user guidelines; and rapid-response advice to requesting organizations. LESL provided its many services without laboratories of its own—its managers issued contracts for the necessary laboratory work to capable groups elsewhere within the Bureau or outside. Administratively, LESL formed a part of the Center for Consumer Product Technology, Institute for Applied Technology.

The seven major project areas and their chiefs were: communications systems, Marshall Treado; security systems, Lawrence K. Eliason; investigative aids, Robert C. Mills; protective equipment, Ronald C. Dobbyn; courtroom equipment, Raymond L. Falge; vehicles, Jared J. Collard; and specialized systems, Avery T. Horton.

The lion's share of LESL support—more than 90 %—came from the National Institute for Law Enforcement and Criminal Justice. Smaller amounts came from the National Highway Traffic Safety Administration and the Defense Nuclear Agency. By 1975 LESL had produced on behalf of these sponsors more than two dozen reports, 18 performance standards, two Standard Reference Materials, and a user guideline.[66]

Communications Equipment

Laboratory work to improve police communications equipment or to develop more effective new units was centered in the Electromagnetics Division in Boulder. The effort, directed by Marshall Treado, focused on mobile and hand-held radios, base-station electronics, personal transceivers, transmitters for undercover use, vehicle-locating devices, and sensitive voice and broadcast receivers. In each case, field testing was used to prepare performance standards, thus allowing police units to write specifications addressing their particular needs rather than simply requesting items of existing equipment that might or might not satisfy their requirements.[67]

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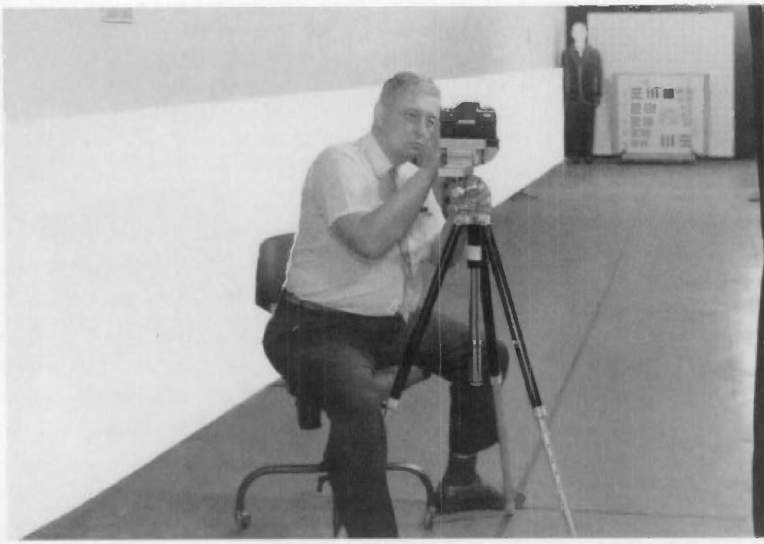
[65] Public Law PL 90-351, 82 Stat. 197, June 19, 1968.

[66] "NBS lab marshals Bureau know-how to help fight crime," *NBS Standard,* July, 1972, pp. 1, 10. See also Jacob J. Diamond, "The Law Enforcement Standards Laboratory," *Dimensions/NBS* **59**, March 1975, pp. 51-53.

[67] Marshall Treado, "Safer Streets Through Improved Communication," *Dimensions/NBS* **59** p. 54, March 1975.



In research for the National Institute of Law Enforcement and Criminal Justice, NBS scientist Joseph C. Richmond adjusted a passive night vision camera in order to photograph an optical chart and a dummy in the Law Enforcement Standards Laboratory.

Legal Record-Keeping

Scientists in the Boulder Electromagnetics Division, under the direction of Raymond L. Falge, studied courtroom use of tape recorders employing both audio and video signals, playback systems, and storage techniques. Much of this equipment was not in common use in U.S. courtrooms, which frequently relied on the older stenographic methods of recording and storage despite their unavoidable uncertainties and delays.[68]

A user guide to recording, replaying, and storage by electronic methods provided a means by which courtroom personnel could design systems to meet their individual needs. Performance standards describing the critical features of recording equipment were developed as well, providing specifications in terms that would satisfy local needs.

The objective of the record-keeping program was to provide the means for any courtroom to record testimony and other needed information in a durable format and to enable courtroom personnel to retrieve the information quickly and to store it efficiently without the danger of loss. In many cases, video recording equipment was found to satisfy courtroom needs far better than previously used methods, allowing

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[68] Raymond L. Falge, "Guidelines For Keeping Better Court Records," *Dimensions/NBS* **59** pp. 56-57, March 1975.

quicker and more accurate acquisition of testimony and preserving lifelike images of witnesses for use long after their departure or demise. Qualities of video images judged most significant were visual resolution, contrast, spectral sensitivity, and freedom from distortion.

Protective Gear

Developing improvements in protective gear for police use was the responsibility of a group operating under the leadership of Ronald C. Dobbyn. Its work encompassed a wide range of equipment. Body armor was one of the first items studied; it was followed by work on helmets, hearing protection, gas masks, face shields, handgun ammunition, and firing-range safety. As with other features of LESL work, the focus was on laboratory evaluation of existing equipment, the development of more satisfactory devices where needed, and the formulation of performance specifications to permit state and local police groups to buy the protection they needed. LESL examined 11 types of riot helmets; only two gave protection to the user that was considered adequate. In preparing typical examples of situations where such gear would be used, NBS scientists devised tests that would determine the forces exerted on helmets by particular objects likely to impact them. This information was then used to develop performance standards useful to many police departments.[69]

Forensic Standards

The increasing dependence of police upon physical evidence to amplify or replace statements of witnesses in turn increased the need for better physical standards for forensic use. Areas studied under the LESL Investigative Aids program, directed by Robert M. Mills, included composition and color of paint for automobiles, glass refractive index and composition, and gunpowder analysis, as well as alcohol detection and quantification.[70] A new Standard Reference Material for glass was developed and produced; a set of 140 automotive paint samples was collected, chemically analyzed, and cataloged;[71] and equipment was developed for use in gunpowder and alcohol detection, parcel screening, and bomb and narcotics detection.

Security Systems

Security systems, as applied to crime work, included an enormous variety of devices. Such mundane objects as doors resided in that group along with burglar alarms, handcuffs, window locks, night-vision viewers, and surveillance cameras. Lawrence K. Eliason led the Bureau effort in this area. One of the first investigations

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[69] Ronald C. Dobbyn, "Helping improve police protection," *Dimensions/NBS* **59**, p. 58, 67, March 1975.

[70] Robert M. Mills, "Toward more objective evidence," *Dimensions/NBS* **59**, p. 59, March 1975.

[71] Charles G. Leete, "Collection of auto paint colors prepared for forensic use," *Dimensions/NBS* **58**, pp. 200-201, September 1974.

Charles G. Leete, Research Associate from the Manufacturers Council on Color and Appearance and co-developer of the NBS Law Enforcement Standards Laboratory automotive paint reference collection, demonstrated the ease of visually matching a paint sample to a vehicle.

LESL performed in the security area involved the evaluation of the effectiveness of handcuffs. The staff found that as little as 27 newtons of force—barely 6 pounds—sufficed to open handcuffs in one shipment received by a state police force. Needless to say, the manufacturer was anxious to replace the entire shipment. LESL produced a draft standard for metal handcuffs based upon testing of actual sample devices.

Examining "thumbcuffs," under consideration as replacements for ordinary handcuffs, the staff found that, to be effective, the cuffs had to be applied so tightly that the prisoner was in danger of losing his thumbs because of severe restriction to the blood supply. A quickly drawn recommendation pointed out the danger in thumbcuffs and suggested that they not be used.

Burglary was estimated to cost the public $750 million per year. The LESL staff found, however, that typical burglar-alarm systems gave up to 99 % false-alarm rates, mostly as a result of improper operator procedures. Examining the detailed functioning of the alarms led quickly to a better understanding of the devices and the preparation of guidelines for their purchase and use.

Other security items under study included door and window locks, an analysis of the abilities of likely forced-entry burglars, and the selection and operation of surveillance cameras.[72]

[72] Lawrence K. Eliason, "Investigating the performance of security systems," *Dimensions/NBS* **59**, pp. 60-62, March 1975.

Vehicles

Jared J. Collard was charged with management of the LESL police vehicle program. He noted some of the many problems encountered in the use of vehicles by typical departments.[73] In compiling an experiential database, NBS surveyed nearly 1400 police agencies; patrol cars were identified as one of the two major equipment problems, not a happy circumstance considering that only police station operating costs and personnel expenses exceeded expenditures for vehicles. Robert G. Massey of NBS initiated a study of the details of police vehicles, including equipment normally carried therein. He found many instances in which departments purchased vehicles simply because of budget restrictions, even though they did not fit the anticipated mode of use.

Rosalie T. Ruegg, a Technical Analysis Division economist, collaborated with the LESL project. She prepared a report reviewing the costs and benefits of repairing or replacing police vehicles as functions of their age and service, basing her work on actual records of police departments. She addressed the advantages and disadvantages of fleet ownership by police units, as well as leasing methods. Ruegg's analysis offered helpful guidelines for hard-pressed police departments.[74]

Properties of Materials

Microbes and the Corrosion of Metals

In 1922, NBS set up a Corrosion Laboratory to augment even-earlier studies of underground corrosion of metallic equipment by stray electrical currents. The new laboratory staff began investigations of the corrosive action of soil itself on buried metal construction components. Utilities, especially gas line companies, were plagued at that time by economic losses arising from corrosion damage to their equipment.[75] Study of underground and underwater corrosion of metals continued apace, both at the Bureau and elsewhere, since that time.[76] Occasional discoveries of new corrosion mechanisms expanded man's understanding of this surprisingly complex phenomenon. One of the more interesting new mechanisms involved microbes, which were found to foster corrosion in as unusual a location as airplane fuel tanks, and, probably, to have hastened or caused the cracking of America's famous Liberty Bell.[77]

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[73] Jared J. Collard, "Patrol car performance and safety studied," *Dimensions/NBS* **59**, p. 63, March 1975.

[74] R. T. Ruegg, "The police patrol car: economic efficiency in acquisition, operation, and disposition," *NBSIR 75-961,* June 1976, 225 pp.

[75] Cochrane, *Measures for Progress,* p. 121.

[76] Warren P. Iverson, "Possible source of a phosphorus compound produced by sulfate-reducing bacteria that cause anaerobic corrosion of iron," *Materials Performance,* May 1998, pp. 46-49.

[77] Warren P. Iverson, private communication to the author.

In 1974, Warren P. Iverson, who was employed as a bacteriologist and microbiologist prior to joining the NBS Metallurgy Division in 1969, received both the Department of Commerce Silver Medal Award and the Charles Thom Award of the Society of Industrial Microbiology[78] for his studies of the role of microbes in underground and underwater metal corrosion. The awards followed a series of publications and talks by Iverson and his colleagues on certain mechanisms by which microbes greatly hastened the rate of corrosion of metallic materials in contact with the earth.[79]

Other members of the Corrosion Section of the Metallurgy Division, led at that time by Jerome Kruger, included Melvin Romanoff (just about to retire after nearly thirty years of corrosion work at the Bureau), William F. Gerhold, W. J. Schwertfeger, Benjamin T. Sanderson and Edward Escalante. Collaborators from the U.S. Army Corps of Engineers and the U.S. Naval Civil Engineering Laboratory included L. L. Watkins and R. L. Alumbaugh.

A microbe-free theory of metallic corrosion in marine environments that related chemisorption and passivity to alloy compositions with particular d-electron configurations was presented at the same time by Lawrence H. Bennett, Lydon J. Swartzendruber and Michael B. McNeil of the Alloy Physics Section of the Metallurgy Division.[80]

In a related microbe-vs-metal investigation, Iverson joined William R. Blair and Frederick E. Brinckman—colleagues from the NBS Inorganic Materials Division—in a collaboration with Rita R. Colwell of the University of Maryland to study the interactions between mercury and microorganisms found in the Chesapeake Bay.[81]

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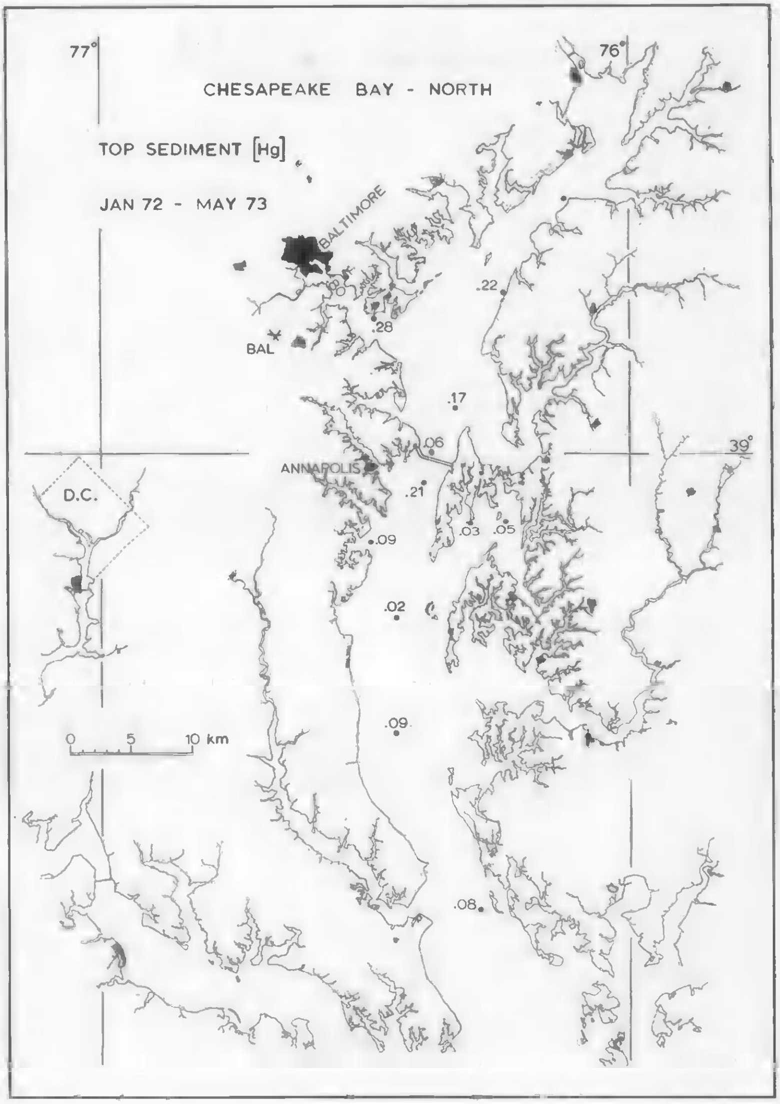
[78] W. P. Iverson, "Anaerobic corrosion: Metals and microbes in two worlds," *Dev. Ind. Microbiol.* **16**, 1-10 (1975).

[79] W. P. Iverson, *Biological Corrosion,* Chapter in *Advances in Corrosion Science and Technology,* M. G. Fontana and R. W. Staehle, Editors, **2**, pp. 1-42 (Plenum Press, New York, 1972). See also W. P. Iverson, "Tests in Soils," (Proc., Symposium on State-of-the-Art in Corrosion Testing, ASTM Annual Meeting, June 21-26, 1970, Toronto, Canada). Chapter 21 in *Handbook on Corrosion Testing and Evaluation,* W. H. Ailor, Ed., (John Wiley & Sons, Inc., New York, 1971) pp. 575-597. See also W. P. Iverson, "The corrosion of mild steel by a marine strain of *Desulfovibrio,*" *Proc. 3d Int. Congress on Marine Corrosion and Fouling, Gaithersburg, Md, Oct 2-6, 1972,* Northwestern University Press, Evanston, Ill., Oct 1973, pp. 61-82. See also W. P. Iverson, "Microbial corrosion of iron," Chapter 19 in *Microbial Iron Metabolism,* Neilands, Ed., (New York: Academic Press, 1974) pp. 475-513.

[80] L. H. Bennett, L. J. Swartzendruber and M. B. McNeil, "On the electron-configuration theory of marine corrosion," *Proc. 3d Int. Congress on Marine Corrosion and Fouling, Gaithersburg, Md, Oct 2-6, 1972,* Northwestern University Press, Evanston, Ill., Oct 1973, pp. 410-426.

[81] W. R. Blair, W. P. Iverson and F. E. Brinckman, "Application of a gas chromatograph—atomic absorption detection system to a survey of mercury transformations by Chesapeake Bay microorganisms," *Chromosphere III,* No. 4, 167-174 (1974).

In 1949, Melvin Romanoff of the NBS Corrosion Section removed and inspected test specimens at a corrosion test site at Loch Raven, Maryland. Romanoff, an internationally known expert on underground corrosion, joined NBS in 1937; except for a year's military service during World War II, he worked at the Bureau until his death in 1970.



Map showing concentrations of mercury in top sediment of the Chesapeake Bay between January 1972 and May 1973. The element was most prevalent near population centers and industrial sites.

Cavitation in Mechanical Failure

The Mechanical Failures Prevention Group, formed during the 1960s under the sponsorship of the Bureau's Metallurgy Division to study ways of mitigating various types of failure in mechanical systems, met on Halloween in 1973 at NBS in Boulder.

It was the 19th meeting of the organization, sponsored by the Office of Naval Research, the National Aeronautics and Space Administration, and the NBS Institute for Materials Research.

The topic of the meeting was cavitation and mechanical failure. Sixteen papers were presented during the three-day meeting. They covered such topics as the physics of cavitation damage to materials, practical examples of cavitation erosion, cavitation in particular fluids, and coatings and other means to prevent cavitation damage.[82]

Fracture in Ceramics

A detailed analysis of slow crack growth in ceramics at temperatures up to 1400 °C was published by A. G. Evans. He discussed both cyclic and static loading conditions, using available data to account for and to predict failures. He discovered that purity of the ceramic was a key element in preventing failure, and that plasticity—leading either to motion of dislocations or to grain-boundary sliding—was a primary factor in the growth.[83]

Sheldon M. Wiederhorn performed a similar study of fracture in glass. Reviewing factors affecting the strength of glass—brittleness, surface flaws, and stress corrosion cracking—Wiederhorn applied the ideas of fracture mechanics to the physics and chemistry of glass strength. He expected that approach to aid in the design of glass structures.[84] The study relied heavily upon an earlier investigation by Wiederhorn and Leonard H. Bolz which employed the methods of fracture mechanics to stress corrosion cracking of glass.[85]

In the earlier work, Wiederhorn and Bolz measured crack velocities as a function of applied stress and temperature. They were able to determine activation energies for crack motion, which they found to be consistent with a universal static-fatigue curve for glass.

Ultra-Pure Materials

Recognizing that contamination of ultra-pure refractory materials by containers was a major problem in the preparation of ultra-pure materials, Alan L. Dragoo and Robert C. Paule considered the advantages of purification in a space environment. As an

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[82] "MFPG. The role of cavitation in mechanical failures," *NBS Special Publication 394,* 183 pp., April, 1974, T. R. Shives and W. A. Willard, editors.

[83] A. G. Evans, "High temperature slow crack growth in ceramic materials," *NBSIR 74-442,* 48 pp., February, 1974.

[84] S. M. Wiederhorn, "Strength of glass—a fracture mechanics approach," *NBSIR 74-485,* 24 pp., May 1974.

[85] S. M. Wiederhorn and L. H. Bolz, "Stress corrosion and static fatigue of glass," *J. Amer. Ceram. Soc.* **53**, No. 10, 543-548 (1970).

illustrative example they studied the advantages for the evaporative purification of molten alumina in zero gravity. They concluded that many thermodynamic criteria would still apply, but with modifications needed to account for weightlessness and reduced pressure.[86]

Stable Lasers, Frequency Standards, the Speed of Light, and New Laser Physics

The Elusive Speed of Light

How fast does light travel? This question fascinated mankind for centuries. Early attempts to measure the elusive quantity, such as the famous timing experiment proposed by Galileo in which lanterns on adjacent mountain tops would be unmasked in sequence, could only prove that light did indeed travel quickly.

Physicists found the speed of light to be an especially compelling constant of nature. Apart from its intrinsic interest, knowledge of the quantity was useful in many physical laws as, for example, when electromagnetic radiation was employed in "ranging" problems—determining distances, either between distant places on the earth or between celestial bodies such as the earth and the moon. An example of this use of the speed of light was presented in Chapter 2 (Lunar Ranging).

As of 1970, the speed of light was known with an uncertainty of a few parts in ten million. For example, a determination of the speed of light was performed in 1958 by K. D. Froome, a physicist at the National Physical Laboratory in England, using a radio interferometer. In his report, he gave as the uncertainty three parts in 10^7 at best. In a monograph summarizing the experiment, Froome and a colleague, L. Essen, stated the nub of the measurement problem succinctly:[87]

> The merits of the optical interferometer for the precision measurement of length or, conversely, the radiation wavelength, are well-known and require no elaboration here. But an interferometer operating with a radiation whose frequency *can be measured* offers an extremely accurate method for the determination of the velocity of this radiation.

To experiment with a form of radiation whose frequency and wavelength could readily be measured, Froome chose to use microwaves of 72 GHz frequency.

Given the difficulty of their measurements, it startled the scientific community when an announcement was made during a press conference in Denver, Colorado, on January 28, 1972 that Richard L. Barger, Bruce L. Danielson, Gordon W. Day, Kenneth M. Evenson, John Hall, F. Russell Petersen, and Joseph S. Wells, using a methane-stabilized laser of known frequency and wavelength, had derived a new value for the speed of light—one with an uncertainty of about three parts in 10^9. The new value was given as $(299{,}792{,}456.\ 2 \pm 1.1)$ meters per second.

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[86] A. L. Dragoo, and R. C. Paule, "Ultrapure materials; containerless evaporation and the roles of diffusion and Marangoni convection," *Proc. 12th Aerospace Sciences Meeting, Washington DC, Jan 30-Feb 1, 1974,* paper No. 74-209, pp. 1-8.

[87] K. D. Froome and L. Essen, *The Velocity of Light and Radio Waves,* (New York: Academic Press, 1969) pp. 136-137.

In 1972, Kenneth M. Evenson was photographed with the apparatus used to measure the frequency of an infrared helium-neon laser, the highest frequency measurement made to that time. Since the wavelength had already been determined in terms of the ^{86}Kr standard, knowledge of the frequency permitted calculation of the speed of light with greatly improved accuracy.

A news report of the Denver announcement was carried in the New York Times on January 31, 1972.[88] The German periodical Der Spiegel carried a similar report on February 14, 1972.

A brief publication of the new, high-frequency, speed-of-light measurement first appeared in the scientific literature late in 1972.[89]

The seven Boulder physicists shared the 1974 Department of Commerce Gold Medal Award for their work.

Key to the *tour de force* of the "Boulder seven" clearly was to devise an accurate measurement of both the wavelength and frequency of the radiation from the methane-stabilized laser.[90] Their success was an interesting example of the power of cohesive effort by a group of dedicated physicists. In a few short years they accomplished scientific work that could easily have taken more than a decade.

[88] Collier N. Smith, "NBS scores measurement breakthrough," *NBS Standard Vol XVII*, No. 3, April 1972, p. 1.

[89] K. M. Evenson, J. S. Wells, F. R. Petersen, B. L. Danielson, G. W. Day, R. L. Barger, and J. L. Hall, "Speed of light from direct frequency and wavelength measurements of the methane-stabilized laser," *Phys. Rev. Lett.* **29**, No. 19, 1346-1349 (1972).

[90] A short but informative account of this work is given by Wilbert F. Snyder and Charles L. Bragaw, *Achievement in Radio*, pp. 634-637.

In 1974, seven physicists from the NBS Boulder laboratories received the Department of Commerce Gold Medal Award for their work on frequency and wavelength standards and for a re-determination of the speed of light. Standing, from the left, are Richard L. Barger, John L. Hall, F. Russell Petersen, and Joseph S. Wells. Seated, from the left, are Kenneth M. Evenson, Bruce L. Danielson, and Gordon W. Day.

Laser Stabilization

One of the first problems to be faced was to stabilize a short-wavelength laser at a totally new level of reproducibility. Early in the project, John L. Hall, one of Lewis Branscomb's first colleagues in the Joint Institute of Laboratory Astrophysics, outlined the problem of deriving wavelength standards from lasers that periodically experienced frequency shifts as large as ten thousand times the theoretical bandwidth. Since the instability affected both the wavelength and the frequency, one could discuss the problem from either point of view. Hall also proposed a solution to the problem.[91]

In his paper, Hall noted that, while the intrinsic spectral bandwidth predicted for gas lasers might be as small as 10^{-13} of its wavelength or even less, the "resettability" of such lasers was typically one part in 10^9. The solution, he stated, was to incorporate

[91] J. L. Hall, "The laser absolute wavelength standard problem," Paper P-1 at the *1968 International Quantum Electronics Conference, May 14-17, Miami, Florida.* Published in *IEEE J. Quantum Elec.* **QE-4**, No. 10, pp. 638-641 (1968).

in the laser a servomechanism that would continually reset the oscillating cavity to some precise feature in the radiant spectrum of the system.

Hall mentioned several possibilities for stabilizing existing lasers: the Lamb dip associated with the 632 nm He-Ne laser, stable within perhaps one part in 10^9, except for pressure effects; dispersion stabilizers based on gain-modulation frequency shifts; and atomic or molecular lines in tag gases included in the laser. He mentioned work done with Harold S. Boyne on Lamb-dip stabilization on the 1 μm neon line, as well as work done elsewhere on an iodine line at 514 nm, which would appear later in a stabilizing scheme. Finally, he referred to work under way with Richard Barger on a 3.39 μm line in methane, which would figure directly in the redefinition of wavelength and frequency standards as well as help provide a greatly improved value for the speed of light.

Barger and Hall attacked the stabilization problem head-on. They showed in 1969 how to obtain a methane line with half-width-at-half-maximum-intensity of approximately 10^{-9} and how to stabilize to the center of the line within about one part in 10^{11}. This level of irreproducibility, the best found up to that time, was less than 1 % of the uncertainty of the then-primary length standard, the 605.7 nm line of ^{86}Kr.[92] The methane line showed exceptionally small shifts arising from changes in pressure or temperature. Furthermore, Barger and Hall found that only modest power densities and moderate laser-line pressure shifts were needed to make use of the line for stabilization of the helium-neon laser. Such a stabilized laser would provide a reproducible radiation source at 88 THz and 3.39 μm, very useful values if they could be measured accurately.

In 1971, Barger and Hall shared the NBS Stratton award for "extraordinary creativity in the application of lasers to the science of measurement."[93] Barger and Hall had utilized the methane-stabilized helium-neon laser for new length measurements. Their work was only part of the flood of laser-based physics that came from the Boulder laboratories in that period.

Frequency Measurement

Obtaining an accurate value for the frequency of the methane line presented a difficult hurdle. There was a large difference in frequency between the methane line and the existing cesium-beam standard. The high optical frequencies of laser lines seemed out of reach.

Evenson and his colleagues overcame the calibration problem by constructing a "chain" of overlapping frequency measurements. In February 1970, Evenson, Wells, Lawrence M. Matarrese, and Lyman B. Elwell reported measurements of the absolute frequencies of two water-vapor laser lines, at 3.8 THz and 10.7 THz.[94] They used a

[92] R. L. Barger and J. L. Hall, "Pressure shift and broadening of methane line at 3. 39 μ studied by laser-saturated molecular absorption," *Phys. Rev. Lett.* **22**, No. 1, 4-8 (1969).

[93] "Stratton and Rosa awards presented," *NBS Standard,* Vol XVI, No. 6, June 1971, p. 1.

[94] K. M. Evenson, J. S. Wells, L. M. Matarrese, and L. B. Elwell, "Absolute frequency measurements of the 28- and 78-μm cw water vapor laser lines," *Appl. Phys. Lett. 16,* No. 4, 159-161 (1970). The correct interpretation of the water vapor laser lines—and the HCN laser lines as well—was provided by David R. Lide, Jr. and Arthur G. Maki, "On the explanation of the so-called CN laser," *Appl. Phys. Lett.* **11**, p. 62 (1967).

"catwhisker diode" comprised of tungsten on nickel to achieve harmonic generation and mixing of the water-vapor laser lines with radiation from an HCN laser and from phase-locked klystron tubes. They found proper adjustment of the diode to be "onerous." However, the two frequency measurements made thereby were evaluated in comparison to the NBS cesium-beam frequency standard, with an estimated uncertainty of 1 ppm and 0.2 ppm, respectively. These were the highest frequency calibrations yet reported.

The new high-frequency record lasted only a few weeks. Using the same point-contact diode technique to detect beat frequencies, Evenson, Wells and Matarrese reported in March 1970 yet higher frequency measurements, this time of lines in the 28 THz branch of the CO_2 cw (continuous-wave) laser.[95] The measurement was made possible by use of the 3.8 THz and 10.7 THz lines of the water-vapor laser, and a klystron operating from 26 GHz to 28 GHz. The balky diode was even less stable at the higher frequency, but two lines were measured at 28.3 THz with an uncertainty of 1 ppm.

The next step in this frequency-measurement odyssey was completed in late 1971 by Evenson, Day, Wells, and L. O. Mullen, with measurements of the frequency of the 88 THz methane stabilization line in the helium-neon laser.[96] Once again, the Boulder team broke the record for the highest absolute frequency measurement. Radiation from a CO_2 laser and a 50 GHz klystron were used along with the He-Ne radiation to make the measurement, with harmonic generation and mixing again occurring in a tungsten-on-nickel diode. The resulting uncertainty was quoted as 0.6 ppm.

The accuracy of the frequency measurements reported thus far had been limited by the way in which the lasers were tuned. Evenson, Wells, Petersen, Danielson, and Day[97] were able to improve the accuracy of the measurements substantially—as much as 100 times—by tuning them to molecular transitions in CO_2 and CH_4. In the paper cited in the previous paragraph, the authors described the entire calibration chain, from the cesium-beam frequency standard as maintained by NBS to the 88 THz methane line. The frequency chain, a three-step process, had required the manipulation and careful measurement of five different lasers and five klystron sources. In step 1, an HCN laser was frequency-locked to a quartz crystal oscillator, using two klystrons; the H_2O laser was frequency-locked to the stabilized CO_2 laser and the beat frequency between the H_2O and HCN lasers was measured. In step 2, the difference between the two CO_2 lines was measured. In step 3, the frequency of the 3.39 μm line in methane was measured relative to one of the lines of the CO_2 laser. Values for each of the three measured molecular transitions were given, with uncertainties ranging from 1 to 1.5 parts in 10^9.

[95] K. M. Evenson, J. S. Wells, and L. M. Matarrese, "Absolute frequency measurements of the CO_2 cw laser at 28 THz (10.6 μm)," *Appl. Phys. Lett.* **16**, No. 6, 251-253 (1970).

[96] K. M. Evenson, G. W. Day, J. S. Wells, and L. O. Mullen, "Extension of absolute frequency measurements to the cw He-Ne laser at 88 THz (3.39 μ)," *Appl. Phys. Lett.* **20**, No. 3, 133-134 (1972).

[97] K. M. Evenson, J. S. Wells, F. R. Petersen, B. L. Danielson, and G. W. Day, "Accurate frequencies of molecular transitions used in laser stabilization: The 3.39 μm transition in CH_4 and the 9.33- and 10.18 μm transitions in CO_2," *Appl. Phys. Lett.* **22**, No. 4, 192-195 (1973).

Wavelength Measurement

The measurement of the wavelength of the stabilized methane line at 3.39 μm was the final piece of the speed-of-light accomplishment. Barger and Hall, who had demonstrated the stability of the line, also measured its wavelength.[98] They used a frequency-controlled Fabry-Perot interferometer for the purpose. It was necessary to compare the methane-line wavelength to the length standard, the line of ^{86}Kr defined to be 605.7802105 nm.

The uncertainty of the Kr standard was limited by an asymmetry in the standard line. This asymmetry was discovered only after the frequency of the line had been defined by international agreement. Because of the standard line asymmetry, the methane wavelength was given by Barger and Hall as 3.392231404 μm and 3.392231376 μm. The two values represented the wavelength of maximum intensity of the Kr line and the center of gravity of the line, respectively. The uncertainty of the measurement was estimated as ± 3.5 in 10^9.

A New Value for the Speed of Light

The assumption underlying the entire project was that the product of the frequency and wavelength of an electromagnetic wave truly represented the speed of propagation of that wave. With absolute values available for both the wavelength and the frequency of the methane line used in the experiments, all that remained to provide a new value for the speed of light, in principle, was a simple multiplication. Evenson, Wells, Petersen, Danielson, Day, Barger, and Hall provided that final step in the letter to the Physical Review that was mentioned earlier.[99]

In their paper, the Boulder group referred to the utility of stable, reproducible lasers as references for both frequency and wavelength. They also noted that the methane-stabilized helium-neon laser operating at 3.39 μm and 88 THz could provide these references in the range where precision could be optimized, and they reviewed the methods used for calibration of both wavelength and frequency of the methane line. They called attention once again to the characteristics of the length standard that limited its accuracy. In order to minimize the uncertainty of the speed of light resulting from their measurements, the group selected one feature of the ^{86}Kr line—its center of gravity—which they found that they could identify within ± 3.5 parts in 10^9. That uncertainty then dominated the overall determination of the speed of light, given as $c = (299\,792\,456.2 \pm 1.1)$ m/s.

The new determination of the speed of light agreed with the previous value, but carried a lower uncertainty by nearly a factor 100. Their result also agreed with a new value simultaneously presented by an NBS Gaithersburg group (see below). In order to

[98] R. L. Barger, and J. L. Hall, "Wavelength of the 3.39-μm laser-saturated absorption line of methane," *Appl. Phys. Lett.* **22**, No. 4, 196-199 (1973).

[99] K. M. Evenson, J. S. Wells, F. R. Petersen, B. L. Danielson, G. W. Day, R. L. Barger, and J. L. Hall, "Speed of light from direct frequency and wavelength measurements of the methane-stabilized laser," *Phys. Rev. Lett.* **29**, No. 19, 1346-1349 (1972).

make best use of the new results, the group recommended that consideration be given to revising the length standard by assigning a particular value to the wavelength of one of the optically stabilized lasers. As an alternative, they noted that the speed of light could be set by international agreement and the wavelength of the lasers set by experiment. Their paper provided a fitting and well-stated conclusion to a group project that was brilliantly conceived and carefully carried out.

A "Gaithersburg" Value for the Speed of Light

As happens frequently in science, while the NBS Boulder group was in the midst of its re-determination of the speed of light, a second re-determination—quite independent of the first—was in progress in the Bureau's Gaithersburg laboratory.

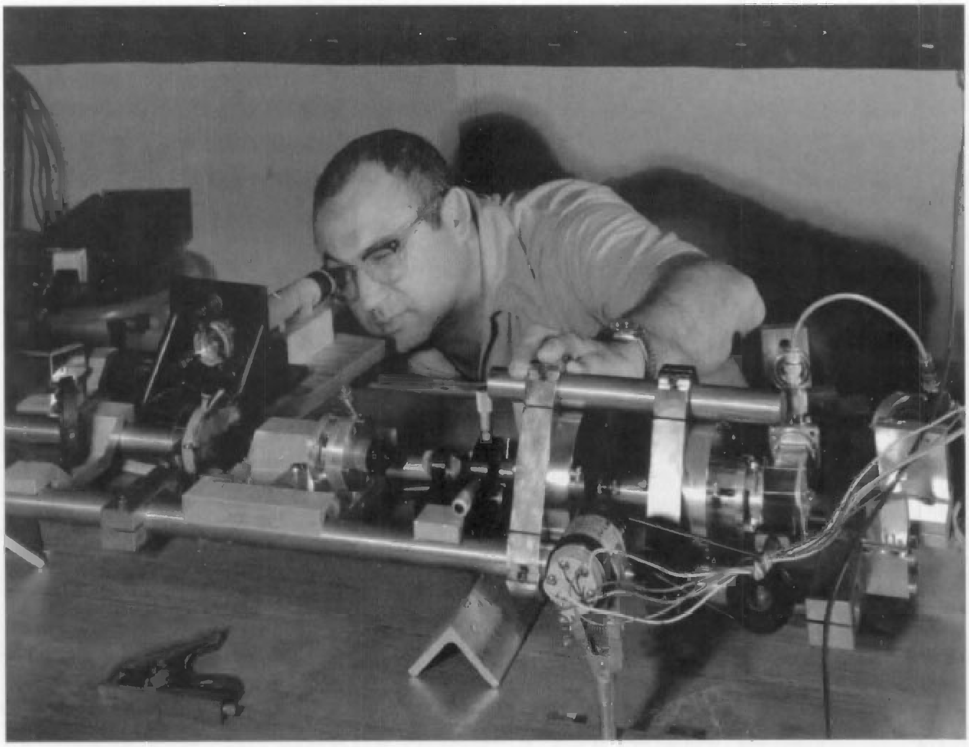
Zoltan Bay and Gabriel G. Luther of the Quantum Metrology Section of the Optical Physics Division, in collaboration with John A. White, a colleague from The American University, published a new value for the speed of light a few months before the Boulder group.[100] The Gaithersburg group used an ingenious scheme for modulating the light from the 633 nm line of a helium-neon laser by the use of microwaves. The technique produced the frequency difference between sidebands generated by the modulation process, as well as the ratio of the frequencies of the sidebands. The frequency of the laser line was thus calculated in terms of the microwave frequency, which could be measured directly in terms of the primary standard of frequency at 100 kHz.

The value given for the red-line frequency was $\nu = (473\ 612\ 166 \pm 29)$ MHz or slightly in excess of 473 THz. Using a value for the wavelength of the He-Ne red line given earlier by Christopher Sidener of the Bureau's Optical Physics Division, $\lambda = (632.991\ 47 \pm 0.000\ 01)$ nm, Bay, Luther, and White obtained for the speed of light the value $c = (299\ 792\ 462 \pm 18)$ m/s. This value, while not determined with the low uncertainty level claimed a few months later by the Boulder group, was entirely consistent with their result.

Thus it happened that, within the short space of a few months in 1972, two independent determinations of the speed of light shone forth from NBS, each providing an unprecedented level of uncertainty for one of the most prized of the fundamental constants.

The Task Group on Fundamental Constants, Committee on Data for Science and Technology (CODATA) of the International Council of Scientific Unions included in its report of August 10, 1973, the speed of light as evaluated by the Boulder group. Meeting in October of the same year, the Consultative Committee for the Definition of the Meter (the operative arm of the International Committee for Weights and Measures (CIPM) in the area of length) recommended that the CIPM consider adoption of the 3.39 μm methane transition studied by the Boulder group as a length standard.

[100] Z. Bay, G. G. Luther, and J. A. White, "Measurement of an optical frequency and the speed of light," *Phys. Rev. Lett.* **29**, 189 (1972).



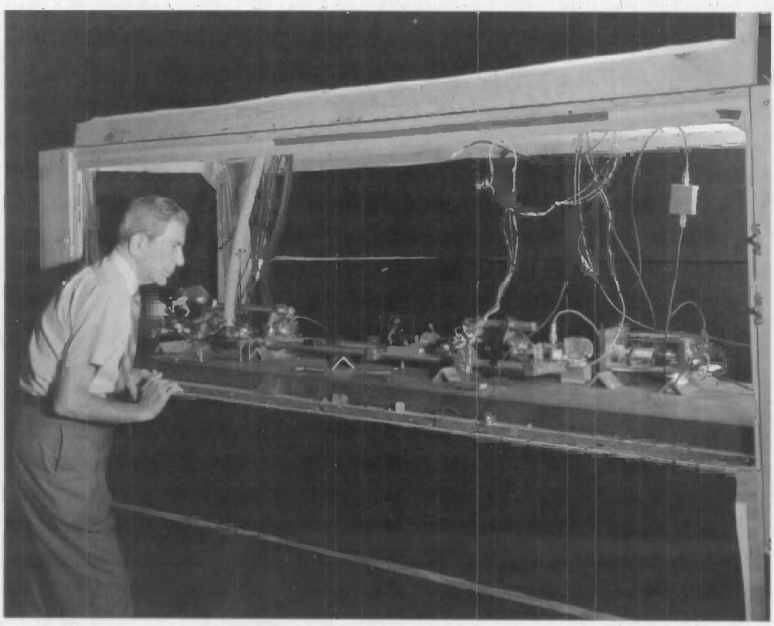
Fine optical adjustments were made by Gabriel G. Luther of the NBS Optical Physics Division during measurements of the optical frequency of the 633 nm red line of a helium-neon laser.

As might have been expected, development of new, more precise measures for length and frequency led to many new measurements and discoveries not directly related to the speed of light. It is interesting to highlight some of these to indicate the type of "spinoff" scientific results that nearly always accompanied advances in metrology.

Lasers and Magnetic Resonance

One of the first of these was the use of lasers in magnetic resonance. Evenson and Wells collaborated with Herbert P. Broida and Robert J. Mahler of NBS and with Masataka Mizushima of the University of Colorado in using an HCN laser to observe paramagnetic resonance absorption in molecular oxygen.[101] Mizushima had noted the coincidence between certain oxygen energy-level separations and the HCN laser frequency at 890 GHz, given the application of a magnetic field of the proper strength.

[101] K. M. Evenson, H. P. Broida, J. S. Wells, R. J. Mahler, and M. Mizushima, "Electron paramagnetic resonance absorption in oxygen with the HCN laser," *Phys. Rev. Lett.* **21**, No. 15, pp. 1038-1040 (1968).



Zolton Bay studied the apparatus used to measure the frequency of a helium-neon laser line.

The successful experiment provided the first observation of absorption between the oxygen levels. It opened a new window into molecular spectroscopy.

Acting on the results of their experiment, Wells and Evenson constructed an improved electron paramagnetic resonance spectrometer based on the use of the HCN laser.[102] The new spectrometer featured a sample cavity that was integral with the HCN laser, separated only by a polyethylene membrane. Its signal-to-noise ratio was higher than the earlier version by a factor of ten or more. Many investigators were attracted to the Boulder laboratory by the prospect of using it.

The new tool was soon put to use by Evenson and Wells in collaboration with Harrison E. Radford, a staff member of the NBS Heat Division until 1970 when he joined the Smithsonian Astrophysical Observatory. Evenson, Wells and Radford investigated the 79 μm electric dipole spectrum of OH, a free radical which they suspected might participate in stellar maser action.[103] Use of the technique enabled the authors to identify an energy coincidence between the OH lines and a line in water, confirming the possibility of maser pumping involving OH.

[102] J. S. Wells and K. M. Evenson, "A new LEPR spectrometer," *Rev. Sci. Instrum.* **41**, No. 2, p. 226 (1970).

[103] K. M. Evenson, J. S. Wells and H. E. Radford, "Infrared resonance of OH with the H_2O laser: a galactic maser pump?" *Phys. Rev. Lett.* **25**, No. 4, 199-202 (1970).

Evenson, Radford and M. M. Moran, Jr., another colleague at the Smithsonian Astrophysical Observatory, quickly investigated yet another interesting case. They identified the fundamental hydrocarbon radical CH, long since known to astronomers by its optical interstellar absorption lines. The radical was expected to appear in the microwave spectrum in the form of a 10 cm Λ-type doubling spectrum, but it had proved singularly elusive in the laboratory. The group was successful immediately with the technique of laser magnetic resonance, using an oxyacetylene flame burning within a water laser. They took advantage of the coincidence between the separation of rotational levels in the CH radical and the 118.6 μm line of the water laser, using a 2 T magnetic field to Zeeman-split the levels and permit the observation of some 14 lines in the CH spectrum.[104]

The lines appeared at the expected positions and with excellent signal-to-noise characteristics (250:1).

The HCN laser spectrometer was used again by R. F. Curl, Jr. of Rice University in collaboration with Evenson and Wells for study of the spectrum of NO_2. The NO_2 molecule, a paramagnetic asymmetric rotor, had Zeeman components at 337 μm and at 311 μm; four lines were quickly identified because their energies could be accurately predicted from previous work.[105] By the time that work was complete, the new technique of laser magnetic resonance was well established.

An interesting feature of the laser magnetic spectrometry was the initial difficulty encountered in interpreting the signals arising from spectrometry of polyatomic molecules. No general formalism existed for the treatment of such data.

Jon T. Hougen, theoretician in the Optical Physics Division, undertook to solve the problem. Using the methods of mathematical physics, he developed equations involving both Zeeman line positions and Zeeman line intensities for the molecular infrared spectra obtained by laser magnetic spectrometry.[106] On the basis of Hougen's work, experimenters could assign quantum numbers and determine spin-rotation interaction constants for the states involved in a given spectral line, without prior knowledge of the molecular structure or the energy levels.

Harmonic Generation

In another "first," harmonic generation up to frequencies of 8200 GHz and submillimeter wave laser detection and radiation mixing in superconducting Josephson junctions were demonstrated by Donald G. McDonald, Evenson, Wells, and J. D. Cupp of NBS, experimenting in collaboration with their colleague from the Physikalisch Technische Bundesanstalt in West Germany, Volkmar Kose.[107]

[104] K. M. Evenson, H. E. Radford and M. M. Moran, Jr., "CH free radicals detected by infrared laser magnetic resonance," *Appl. Phys. Lett.* **18**, No. 10, p. 426 (1971).

[105] R. F. Curl, Jr., K. M. Evenson, and J. S. Wells, "Laser magnetic resonance spectrum of NO_2 at 337 μm and 311 μm," *J. Chem. Phys.* **56**, No. 10, pp. 5143-5151 (1972).

[106] Jon T. Hougen, "The assignment of molecular infrared spectra from a laser magnetic resonance spectrometer," *J. Molec. Spectros.* **54**, 447-471 (1975).

[107] D. G. McDonald, V. E. Kose, K. M. Evenson, J. S. Wells, and J. D. Cupp, "Harmonic generation and submillimeter wave mixing with the Josephson effect," *Appl. Phys. Lett.* **15**, No. 4, pp. 121-122 (1969).

It was known at that time that a Josephson junction could function as a local oscillator and a harmonic generator. The magnitude of the maximum frequency achievable by harmonic generation could be determined by finding the maximum voltage at which a constant-voltage step occurred in the dc voltage-current curve.[108] The NBS/PTB group used a Josephson junction connecting two niobium point contacts to generate constant-voltage steps up to 17 mV (more than 100 steps) in response to an applied radiation at 70 GHz. They also noted that the technique could be used for the direct frequency measurement of infrared laser lines.

Harmonic mixing of klystron and laser radiation, using a Josephson junction, at orders as high as 100—at that time, an unprecedented level—was achieved in 1971 by McDonald, Cupp, Evenson, and their colleague Allan S. Risley.[109] In performing the experiment, they simultaneously irradiated a Nb-Nb Josephson junction with 10 GHz microwaves from a klystron and with 891 GHz laser radiation; a 60 MHz beat note was produced between the fundamental laser frequency and high harmonics of the klystron.

That type of experiment, coupling the properties of the superconducting Josephson junction with applied irradiation, quickly became a standard avenue of investigation.

Detecting Earth-Tides and Nuclear Explosions

Judah Levine, a member of the Quantum Electronics Division in Boulder, and John L. Hall of the Joint Institute for Laboratory Astrophysics constructed a long (30 m) laser strain-meter in an evaluation of the precision of long-path Fabry-Perot interferometry. They built the device underground, in a shaft of an unused gold mine in Boulder County, Colorado. Mounting long-focal-length mirrors on rock piers within a 30 m vacuum tube, they directed the light of a helium-neon laser oscillating at 3.39 μm into the interferometer. A second, similar laser, locked to a particular absorption frequency in methane, served as a reference.

The two scientists found, as expected, that the sensitivity of the system depended in part on the stability of the reference laser, about 1 part in 10^{11}. In part, the sensitivity depended also on the signal-to-noise ratio of the long-path interferometer, which turned out to be about 500 to 1 for a 1 ms integration time. They also had to consider the possibility that the geological response of the rock comprising the area in which the mine was located might exhibit unexpected behavior. They examined this possibility by creating artificial "seismic disturbances" with a sledge hammer. The response of the detector showed no resultant hysteresis or permanent offset, but it did display a directional sensitivity.

[108] See, for example, W. H. Parker, D. N. Langenburg, A. Denenstein, and B. N. Taylor, "Determination of *e/h*, using macroscopic quantum phase coherence in superconductors. I. Experiment," *Phys. Rev.* **177**, 639 (1969).

[109] D. G. McDonald, A. S. Risley, J. D. Cupp, and K. M. Evenson, "Harmonic mixing of microwave and far-infrared laser radiation using a Josephson junction," *Appl. Phys. Lett.* **18**, No. 4, pp. 162-164 (1971).

The authors used their new, wide-bandwidth, stable, highly sensitive strain-meter to study long-term changes in the local earth strain field, the earth tides, and actual seismic events. They found the fact that the strain-meter output was a frequency rather than a voltage to be an advantage, as was its digital nature. The earth tide showed a strain of about 3 parts in 10^8, easily detected with their device.

Fortuitously, they also were able to detect a nuclear explosion. "Project Boxcar," one of a series of nuclear tests, took place in Nevada during their studies. Its transient disturbance of the local geology was readily detected by the Levine-Hall device.[110]

Progress in Physical Standards

Standards, as we have seen, take a variety of forms. Quantities that serve as benchmarks are standards, as are procedures adopted to produce specific results. Some of these we see in this section.

Fundamental Constants

Published in the second volume of the *Journal of Physical and Chemical Reference Data* was the 1973 version of the fundamental constants of physics. It contained the latest recommended values for the dozens of constants that defined the scientific world at that time. Prepared by Barry N. Taylor—a member of the staff of the director of NBS and soon to become chief of the Electricity Division—and E. Richard Cohen of Rockwell International, the summary represented critical reviews and analyses of all the available experimental and theoretical data. The project was carried out under the auspices of a panel of measurement experts operating under the aegis of the Committee on Data for Science and Technology (CODATA), an arm of the International Council of Scientific Unions.

One of the constants upgraded in the summary was the speed of light, determined with greatly improved accuracy by a group of NBS researchers as described earlier in this chapter. All older determinations were discarded in favor of the new value, which featured an uncertainty smaller by a factor of about 75.

In assessing the most probable values for the various constants, Taylor and Cohen used the method of "least squares," involving a comparison of different experimental determinations of the constants to minimize the overall uncertainties.[111]

Values of the 1973 Least-Squares Adjustment of the Fundamental Physical Constants were made available to the general public in a number of different forms, including a wallet card for handy reference.[112]

[110] J. Levine and J. L. Hall, "Design and operation of a methane absorption stabilized laser strainmeter," *J. Geophys. Res.* **77**, No. 14, 2595-2609 (1972).

[111] E. R. Cohen and B. N. Taylor, *J. Phys. Chem Ref. Data* **2**, No. 4, pp. 663-734 (1973).

[112] B. N. Taylor, "Fundamental physical constants," *NBS Special Publication 398,* card, August, 1974.

The National Measurement System

How important are measurements to America? Attempting to answer this question involved many Bureau scientists in a multi-year assessment project that covered nearly two dozen measurement areas.

The elements of a national measurement system were described in 1965-1966 by Robert D. Huntoon,[113] although his discussion dwelled mainly on the degree of sophistication of the various measurement standards in relation to use of atomic and molecular properties as compared to dependence upon artifacts such as the kilogram standard for mass.

During the tenure of Richard Roberts, the concept itself was sufficiently advanced that economists as well as scientists could contribute to answering the question that opened this section. The measurement tools and their accuracies were only one component of the question for specialists in measurement. Of equal interest were the numbers of Americans who themselves made measurements as part of their jobs, the value of the measurement tools employed by those workers, the amount of money spent in making measurements, and the portion of the gross national product resulting from the measurement activity.

Many measurement areas were involved in the study, including the following:[114] dimension; volume & density; temperature; pressure & vacuum; time & frequency; acoustics; vibration & shock; force; humidity; flow; optics; electricity; surface finish; vacuum ultraviolet radiation; spectrophotometry; radiometry & photometry; quantum electronics; x & nuclear radiation; dosimetry; cryogenic material properties; and electromagnetic radiation. The individual reports were published separately as they were completed.

The Bureau technical experts who performed the evaluations of their measurement disciplines and wrote the reports were assisted by several people and organizations. Directing the study was a Presidential Exchange Executive from the Dow Chemical Corp, James Seed, who was assigned to the NBS Director's office for the duration of his tour at the Bureau.[115] Economists from the NBS Programs Office participated, as did the U.S. Labor Department and member firms of the National Conference of Standards Laboratories (NCSL).

Officials of the Labor Department provided a wealth of statistics mainly valuable to the study in an overall way but also dealing in detail with certain of the study areas. Their figures indicated an economic impact of American measurement activities in 1973 in excess of $70 billion, all but about $7 billion reflecting labor costs. Measurement costs thus represented about 6 % of the Gross National Product. Annual sales of companies comprising the NCSL exceeded $300 billion; of that amount, it was estimated that NCSL company laboratories invested about $0.23 billion to produce about $20 billion of added value to America's goods and services.

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[113] R. D. Huntoon, "Status of the national standards for physical measurement," *Science* **159**, No. 3693, 169-178 (1965). See also R. D. Huntoon, "The basis of our measurement system," *Phys. Teacher* **4**, No. 3, 113-120 (1966).

[114] "Measuring the National Measurement System," *NBS Tech. News Bull.*, February, 1974, pp. 38-39.

[115] "NBS has presidential interchange executive," *NBS Standard*, March 1973, p. 13.

A fairly typical study, on flow measurements, involved some 200 contacts with trade associations, companies, universities, measurement laboratories, or agencies of the government. The contacts yielded estimates of the various types of flowmeters in use, their adequacy for the intended use, and the economic significance of flow uncertainties in various applications.

Publication of the individual studies generally appeared in NBS Interagency Reports, beginning in 1974. In all cases, the Bureau's measurement groups came to know their clients better. Generally, they also learned useful facts and clients' views about their own services.

A New Optical Radiation Calibration Service

Beginning July 1, 1972, the Heat Division's Optical Radiation Section, headed by Henry J. Kostkowski, offered a revised schedule of radiometric and photometric calibrations.

The new services were listed under "basic," "gage," and "special." NBS had found it necessary to augment its calibration service in the optical-radiation area to satisfy users who needed special arrangements or better calibration accuracy than they could obtain elsewhere. The "basic" calibrations were those considered of fundamental importance to measurements in the two fields—calibrations of spectral radiance, spectral irradiance, irradiance, luminous intensity, and luminous flux. The "gage" calibrations were provided for measurements in which official uncertainty levels had not been assigned, but for which NBS maintained reference standards. In certain "special" cases, the Bureau could offer calibrations of particular instruments or at especially low uncertainties by extra effort; these calibrations would be undertaken only when the results would benefit many users.

A Century of International Metrology

In 1975 the "Convention du Mètre" (Convention of the Meter, the oldest treaty of which the United States was still a signatory) reached the venerable age of 100 years. The original 1875 Convention was accepted by 17 signatory nations:

Argentina	Austria-Hungary	Belgium	Brazil
Denmark	France	Germany	Italy
Peru	Portugal	Russia	Spain
Sweden and Norway	Switzerland	Turkey	
United States	Venezuela		

The treaty consisted of only 14 Articles. These articles created an International Bureau of Weights and Measures (BIPM) in Paris, to be maintained at the common expense of the signatories; an International Committee for Weights and Measures (CIPM) with authority over the BIPM; and a General Conference on Weights and Measures (CGPM) with authority over the CIPM. The Articles also delineated briefly the responsibilities of the three organizations and placed a few conditions on the "contracting states." Regulations regarding financing, personnel, and operation of the standards apparatus were provided in an appendix to the convention.

The Convention proved to be surprisingly durable. Only minor modifications to it were adopted by a second Convention in 1921. As might be expected, the growing need for measurement standards throughout the world brought a multitude of new classes of standards under the purview of the Convention. These were included by simply expanding the activities of the participating organizations.

By 1975, the number of "member states" that had accepted the Convention had risen to 43—those listed above plus the following group:

Australia	Bulgaria	Cameroon	Canada
Chile	Czechoslovakia	Dominican Republic	
Egypt	Finland	German Democratic Republic	
Hungary (now separate from Austria)		India	
Indonesia	Ireland	Japan	Korea
Mexico	The Netherlands	Norway (now separate from Sweden)	
Pakistan	Poland	Romania	South Africa
Thailand	Soviet Union (replacing Russia)		
United Kingdom	Uruguay	Yugoslavia	

The most recent arrival had been Pakistan in 1973. The Treaty roster by then included nearly all of the industrially mature nations.

At NBS, the centennial was celebrated by exhibits on the Convention of the Meter and on the Metric System, which preceded the Convention and helped to give it life. The Bureau also hosted a conference of educators on the teaching of metric units in schools.

A lasting memento of the centennial was a translation into English of the official centennial volume, edited by Chester H. Page—at that time the Coordinator for International Standardization Activities for the Institute for Basic Standards—and Paul Vigoureux of the National Physical Laboratory in England.[116] Following a history of metrology, 10 chapters of the volume described progress in particular standards (mass, length, gravimetry, manobarometry, thermometry, electricity, photometry, radioactivity, x and gamma rays, and neutrons). Appendices contained the text of the Convention, a list of its member states, the membership and officers of the CIPM, the directors of the BIPM, the international system of units, a short history of the metric system, and a list of the publications originating in Convention activities.

[116] "The International Bureau of Weights and Measures 1875-1975," edited by Chester H. Page and Paul Vigoureux, *NBS Special Publication 420,* May 1975, 248 pp.

In recognition of the 1975 centennial, the 15th General Conference on Weights and Measures, held on the BIPM grounds just outside Paris from May 27 to June 3, became a celebration. Separate activities were held in several countries that participated in the work of the treaty, including the NBS festivities mentioned earlier.[117]

Delegates from 43 nations attended the 15th General Conference; they were treated to several commemorative activities. Valery Giscard d'Estaing, President of France, welcomed the delegates. Jean Terrien, head of the International Bureau of Weights and Measures, presided over the conference. The U.S. delegation to the General Conference consisted of Richard Roberts, Director of NBS, and Ernest Ambler, Deputy Director. Ambler, with long experience in metrology, was the official U.S. delegate. He also served on the International Committee for Weights and Measures (CIPM) and was head of the Consultative Committee for Ionizing Radiation.

Besides the Centennial memorial volume mentioned earlier, a second commemorative, a medal, was struck in honor of the occasion. It portrayed on one face the Pavillon de Breteuil, home of the BIPM, and on the other face the base units of the Systeme Internationale (SI, the international system of metric units).

In its regular proceedings, the 15th General Conference passed several resolutions noting progress in the areas of length, mass, time, electricity, and temperature. One such resolution suggested adopting the value 299 792 458 m/s for the speed of light in a vacuum, symbol c; that value was provided by NBS scientists in the landmark investigations described earlier in this chapter. Several delegates suggested that the value for the speed of light—perhaps the most important of the physical constants—might be fixed by definition, allowing the meter and the second to assume values consistent with a defined value of c.

Another resolution noted recent progress in laser science, advances that could be expected to lead to still more precise definitions of both time and length.

Time was the subject of yet another resolution. In that case, the General Conference recognized the many contributions to time standards made by the International Bureau of Time (BIH). Located at the Observatory of Paris during 1919, the BIH had coordinated international time signals ever since. After the adoption of the atomic clock, the BIH had initiated the International Atomic Time (TAI) scale and had begun the use of the "leap second" to synchronize the new scale with the Universal Coordinated Time scale, which was based upon astronomical observations. The resolution also suggested the abandonment of the Greenwich Mean Time Scale, which was no longer needed.

In a fourth resolution, the Conference praised then-current measurements of the gyromagnetic ratio of the proton, which connected electrical standards to atomic constants, and work on the development of a new volt standard based upon the superconducting Josephson effect.

[117] These events and the history that preceded them were discussed briefly in articles in *Dimensions NBS*, successor to *The Technical News Bulletin of NBS*: "The Treaty of the Metre, 1875-1975," pp. 104, 105, 117, Vol. 59, May, 1975; "An International Meeting, A Century Celebration," p. 224, Vol. 59, October, 1975; and "World Conference Updates Vocabulary," pp. 225-227, Vol. 59, October, 1975.

A final resolution expressed approval of on-going studies of the relation between the International Practical Temperature Scale of 1968 and thermodynamic temperatures, and it adopted slight changes in the IPTS-68, which were embodied in a scale revision entitled "IPTS-68 (1975 version)."

During other deliberations of the 15th General Conference, a number of changes in the SI were adopted. These included:

- Two new prefixes as multipliers for units—peta (symbol P) for 10^{15} and exa (symbol E) for 10^{18}. [118]
- A name for the unit of activity of a weakly radioactive source, the becquerel, symbol Bq, with 1 Bq = 1 disintegration or other nuclear transformation per second.[119]
- A name for the unit of absorbed radioactive dose, the gray, symbol Gy, with 1 Gy = 1 joule per kilogram.[120]

Nearly all of the metrological activities discussed during the 15th General Conference on Weights and Measures involved work done at NBS.

Thermometry With Thermocouples

Specialized industries such as food processing, medicine, and steel-making required accurate thermometry at cryogenic temperatures. Thermocouple thermometers constituted a popular type of thermometer for use at low temperatures. To assist the users of cryogenic thermocouples, Larry L. Sparks, Robert L. Powell, W. J. Hall, and J. G. Hust provided reference tables for use with the International Practical Temperature Scale of 1968 for a variety of low-temperature thermocouples, as well as carefully evaluated uncertainty limits.[121]

Several types of thermocouple wires used to manufacture low-temperature thermometers received shorthand designations from the ASTM. These included copper-nickel alloys (type TN), nickel-chromium alloys (type KP), and nickel-aluminum alloys (type KN). Other popular types involved precious-metal alloys.

[118] An example of the use of these prefixes was to express the large amount of energy used in the United States each day; the amount could be expressed as 10^{17} joules, or alternatively as 100 petajoules (100 PJ), or as 0.1 exajoules (0.1 EJ).

[119] The previous unit, the curie (equal to 3.7×10^{10} Bq) would remain the unit of choice for highly radioactive sources such as those used to sterilize food.

[120] This unit was meant for use with quantities substantially larger than the rad (100 rad = 1 Gy).

[121] L. L. Sparks, R. L. Powell, and J. G. Hust, "Reference tables for low temperature thermocouples," *NBS Monograph 124,* June 1972.

The Cryogenics Division physicists tested samples of the various commercially available wires for homogeneity, both chemical and physical, and published reference tables for their use.[122]

Powell, Hall, Sparks, and C. H. Hyink assisted George W. Burns, Margaret G. Scroger, and Harmon H. Plumb of the Heat Division in constructing reference tables for thermocouple thermometers used in promulgating the International Practical Temperature Scale of 1968.[123] Their publication contained tables, analytic expressions, approximations, and explanations for the use of seven types of thermocouples recommended for use in thermometry by the American Society for Testing and Materials. Three noble-metal types, designated S, R, and B, were included, as were four base-metal types, designated E, J, K, and T.

The new reference data reflected changes resulting from the replacement of the 1948 temperature scale, changes in the properties of the thermocouple materials, and improvements in the methods used to fit the data.

Gaithersburg Heat Division scientists Burns, Scroger, and Wilbur S. Hurst used specially built high-temperature, high-vacuum furnaces for testing thermocouple thermometers capable of measurements at temperatures above 2000 °C. The thermocouples, made of refractory metals such as tungsten and rhenium, required special insulating and protective materials, and special care in assembly to avoid rapid degradation in use.[124]

Assigning Values to Mass

Changes in the methods used to assign values to mass standards resulted in a given weight being credited with several different values of mass over a period of time. In order to provide guidance to metrologists on mass assignment, Paul E. Pontius, chief of the Mass, Length, and Volume Section of the Optical Physics Division, prepared a historical summary of weighing methods and periodic changes in the mass system. Pontius also provided instructions for converting a value assigned on one basis to the corresponding value assigned on another.[125]

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[122] L. L. Sparks and J. G. Hust, "Thermoelectric voltage of silver-28 at % gold thermocouple wire SRM 733, versus common thermocouple materials (between liquid helium and ice fixed points)," *NBS Special Publication 260-34* (1972); L. L. Sparks and R. L. Powell, "Low temperature thermocouples; KP, 'normal' silver, and copper versus Au-0.02 at % Fe and Au-0.07 at % Fe," *J. Res. NBS* **76A**, No. 3, pp. 263-284 (1972).

[123] R. L. Powell, W. J. Hall, C. H. Hyink, Jr., L. L. Sparks, G. W. Burns, M. G. Scroger, and H. H. Plumb, "Thermocouple reference tables based on the IPTS-68," *NBS Monograph* **125**, 410 pp., March 1974.

[124] G. W. Burns, W. S. Hurst, and M. G. Scroger, "High reliability, sheathed, beryllia insulated, tungsten-rhenium alloy thermocouple assemblies—their fabrication and EMF stability," *NASA CR-134549*, pp. 1-36, June 1974.

[125] P. E. Pontius, "Mass and mass values," *NBS Monograph* **133**, 39 pp., January 1974.

Margaret G. Scroger connected an absorption roughing-pump system to a high-vacuum oven used in refractory-metal thermocouple research.

New Density Scale

Horace A. Bowman, Randall M. Schoonover, and C. Leon Carroll, members of the Mass, Length, and Volume Section, created a new scale of density for use in calibration.[126] The new scale originated with four samples of single-crystal silicon, for which the scientists determined the density in terms of international standrds of mass and length.

The group had spent several years in planning the experiment on which the new scale would be based. They chose single crystals of silicon as their "working standards" because of the chemical and physical stability of silicon and the relative ease with which it could be handled in density comparisons. An interferometer,

[126] H. A. Bowman, R. M. Schoonover, and C. L. Carroll, "A density scale based on solid objects," *J. Res. NBS* **78A**, No. 1, 13-40 (1974).

developed at the Bureau by James B. Saunders, was used to measure the diameters of a set of steel balls, commercially manufactured as nearly perfect (within 1 ppm) spheres. From the measured diameters, the volumes of the spheres were readily calculated. Measurement of the masses of the balls immediately allowed the group to calculate their densities.

In a newly designed hydrostatic weighing apparatus, the volumes of the silicon crystals were evaluated in terms of the volumes of the steel balls. Once the masses of the crystals were measured, their densities could readily be calculated.

The authors estimated the uncertainty of their density determinations to be about 1 ppm. This figure represented a significant decrease (about a factor ten) below the variation found in recent international density intercomparisons. Equally valuable was the new volumetric-comparison apparatus and the measurement techniques developed by the three metrologists.

Electromagnetic Units

Chester H. Page, chief of the Electricity Division and soon to complete a distinguished scientific career (35 years at NBS when he retired in 1977), took notice of the general lack of understanding of the quantities defining electromagnetic fields in 1974. Observing the paucity of a logically consistent set of definitions of electromagnetic field quantities in textbooks and other educational materials, Page wrote a short but useful treatise on the subject for the *American Journal of Physics.* His contribution included a brief philosophical discussion of the topic and a consistent system of definitions.[127]

Primary Time and Frequency Standards

James A. Barnes, chief of the Time and Frequency Division, and Gerhard M. R. Winkler of the U.S. Naval Observatory collaborated to produce a publication describing the U.S. system of time and frequency standards. Their two organizations had chief responsibility for keeping and disseminating the standards. Barnes and Winkler discussed the methods used to assure consistent values and to provide useful information to all who needed it.[128]

Helmut Hellwig, chief of the Time and Frequency Standards Section, prepared a status report on operating frequency standards, as well as those that were currently under study. He described the levels of accuracy associated with various standards.[129]

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[127] C. H. Page, "Definitions of electromagnetic field equations," *Amer. J. Phys.* **42**, 490-496 (1974).

[128] J. A. Barnes and G. M. R. Winkler, "The standards of time and frequency," *NBS Technical Note 649,* 91 pp., February 1974.

[129] H. Hellwig, "Status report on primary frequency standards," *NBS Technical Note 646*, 15 pp., September 1973.

Using the Superconducting Voltage Standard

Procedures and measurements used to establish a new definition of the U.S. legal volt via the ac Josephson effect were described by Bruce F. Field, Thomas F. Finnegan, and Jan Toots for the metrological community in the journal *Metrologia.*[130] Thin-film tunnel junctions capable of producing a 10 mV output, augmented by high-accuracy voltage comparators, were the primary tools for the new definition.

As noted elsewhere in this volume, the Josephson junction functioned as a frequency-to-voltage converter with the conversion factor equal to $2e/h$, a constant whose value was determined as 483 593.420 GHz/V_{NBS}.

Evaluating X-Ray Wavelengths

Richard D. Deslattes and Albert Henins evaluated the wavelengths of x-ray reference lines (the $K_{\alpha 1}$ lines of copper and molybdenum) through the use of a nearly perfect single crystal of silicon.

A two-step experiment was used by the two physicists to achieve their goal. In the first step they determined the lattice repeat distance of the silicon crystal in terms of the visible wavelength of a stabilized He-Ne laser. In the second, they used the same crystal to diffract the reference x-ray lines, thus calibrating those wavelengths in terms of the laser wavelength.[131]

In 1974, Deslattes was presented the Samuel Wesley Stratton award for his work on length standards.

Progress in Chemistry Research

Chemistry research at NBS included many specialized topics. The following examples touch only a few of these; more are discussed in other sections throughout this chapter.

A New Calorimeter

Late in 1972, Edward Prosen and Marthada Kilday published the details of a solution calorimeter that had been a decade in development.[132] The instrument had been in use for most of that period, including measurements that led to the certification of two Standard Reference Materials for solution calorimetry. However, no archival discussion of its design, construction, and use had been presented. In their 1972 paper, Prosen and Kilday included measurements on the enthalpies of reaction of sulfuric acid with two different hydrates of sodium hydroxide, along with sufficient detail to allow the reader to appreciate the precision of the device.

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[130] B. F. Field, T. F. Finnegan, and J. Toots, "Volt maintenance at NBS via 2e/h; A new definition of the NBS volt," *Metrologia* **9**, No. 4, 155-166 (1973).

[131] R. D. Deslattes and A. Henins, "X-Ray to visible wavelength ratios," *Phys. Rev. Lett.* **31**, No. 16, 972-975 (1973).

[132] Edward J. Prosen and Marthada V. Kilday, "An adiabatic solution calorimeter and measurements of a standard reaction for solution calorimetry," *J. Res. NBS* **77A**, No. 2, pp. 179-204, (1973).

The calorimeter was designed to operate in the temperature range 293 K to 363 K (room temperature to near the normal boiling temperature of water) and to accommodate about 300 mL of solution in a platinum-lined, silver reaction chamber, along with some 3 mL of solid reactant in a platinum sample holder. Variable-speed stirring (200-850 rpm) of the reactants was accomplished by a platinum stirrer. All other parts in contact with the reactants or their vapor were made of platinum as well. A calibrated platinum resistance thermometer, measured using a sensitive Mueller-type resistance bridge, was used to monitor the temperature of the reaction.

An important feature of the calorimeter was an adiabatic shield surrounding the reaction vessel; it was equipped with a heater energized by signals from a six-junction thermocouple thermometer connected so as to respond to slight temperature differences (typically less than 0.1 mK) between the shield and the reaction chamber.

Phase Diagrams For Ceramists

On October 30, 1974, Ernest M. Levin was awarded the Department of Commerce Gold Medal posthumously for his exceptional contributions to the science of ceramics. A Bureau employee for 30 years, Levin had made the study of ceramics his life work. The citation for his award noted Levin's efforts in the field of phase equilibria and immiscibility in glasses, but most especially his contribution to "Phase Diagrams For Ceramists, a standard reference and text book in many university courses."[133]

Recognizing the enormous value of dependable information on phase equilibria in ceramic materials, the American Ceramic Society had published a half-dozen compilations of phase diagrams beginning in 1933 with a contribution from NBS prepared by F. P. Hall and Herbert Insley.[134] Levin and Howard F. McMurdie, both staff members in the NBS Mineral Products Division, had participated in the publication of some of these compilations.

In 1964, the Society published a 600-page book that regularized the presentation of the phase-diagram information. The diagrams themselves—2066 in number—were preceded by a note on temperature scales, a discussion on interpretation of phase diagrams, information on experimental methods, and a bibliography. The book was written by Ernest Levin, Carl R. Robbins, and Howard McMurdie with the editorial assistance of Margie Reser of the Society. A standard format was adopted for presentation of the phase diagrams.

The same authors produced a supplement to "Phase Diagrams For Ceramists" in 1969, with an additional 2000 entries.

[133] "26th Annual Honor Awards Program, U.S. Department of Commerce, 1974. "NIST Historical Collection.

[134] F. P. Hall and Herbert Insley, "A compilation of phase-rule diagrams of interest to the ceramist and silicate technologist," *J. Amer. Ceram. Soc.*, **16**, pp. 455-567 (1933).

Ernest M. Levin, a physical chemist in the Inorganic Materials Division, joined NBS in 1937. His primary scientific interest was high-temperature phase equilibria in refractory oxides. He received both the Silver Medal (1960) and the Gold Medal (1974) from the Department of Commerce in recognition of the high quality of his work.

Another supplement to the text, containing yet another 850 phase diagrams, was in progress in 1974 under the authorship of Levin and McMurdie when both Levin and Ms. Reser, the editor from the American Ceramic Society, became unable to continue the work. Levin died in August of 1974 and Reser in January of 1975. With the assistance of a group of colleagues, including several from NBS, the volume was completed and dedicated to Levin and Reser. Levin had personally been involved in preparing 42 of the diagrams contained in the three volumes.[135]

Prior to publication of the fourth and fifth volumes in the phase diagram series in 1981 and 1983 respectively, a Phase Diagrams for Ceramists Data Center was established at the Bureau under the auspices of the Office of Standard Reference Data. Robert S. Roth and Lawrence P. Cook of the Ceramics, Glass, and Solid State Science Division teamed with Taki Negas of the Chemical Stability and Corrosion Division to write the new volumes, which contained 838 and 663 phase diagrams, respectively.[136] Commentaries on the diagrams were provided by a group of 32 experts.

[135] Robert S. Roth, Mary A. Clevinger, and Deirdre McKenna, *Phase Diagrams for Ceramists: Cumulative Index for Volumes I-V*, (Columbus, Ohio: The American Ceramic Society, 1984).

[136] Robert S. Roth, Taki Negas, and Lawrence P. Cook, *Phase Diagrams for Ceramists Volume IV*, Geraldine Smith, Editor, (Columbus, Ohio: The American Ceramic Society, 1981). See also Robert S. Roth, Taki Negas, and Lawrence P. Cook, *Phase Diagrams for Ceramists Volume IV*, Geraldine Smith, Editor/ACerS, Mary A. Clevinger, Editorial Assistant/NBS, (Columbus, Ohio: The American Ceramic Society, 1983).

Howard F. McMurdie, trained as a chemist, joined NBS in 1928. He officially retired in 1966 after a robust career in x-ray diffraction, but continued work at the Bureau for more than a decade under the auspices of the International Center for Diffraction Data. As this history was written, McMurdie—more than 90 years old—still contributed to NIST projects.

Further volumes in the series were written in 1987, 1989, 1990, 1992, and 1994. Together, they constitute a remarkable contribution from NBS/NIST to the study of ceramics.

Critical Behavior in Gases

Work in the area of statistical physics began in the Heat Division with the formation in 1960 of a section devoted to that topic. Melville S. Green, winner of both a Guggenheim Fellowship and a Fulbright Award for the excellence of his work in the field, was the first chief of the section. Green quickly built a group of considerable stature in the field, including Marjorie Boyd, Martin J. Cooper, Julius L. Jackson, Sigurd Y. Larsen, Raymond D. Mountain, Robert A. Piccirelli, Harold J. Raveche, Baldwin Robertson, and Jan V. Sengers. In 1968, Green left NBS to join the faculty at Temple University; he was succeeded by Raymond Mountain, himself a Department of Commerce Gold Medal winner in 1983.

In one of his last publications at the Bureau, Green collaborated with Maria Vicentini-Missoni, a guest researcher from the University of Rome, Italy, and Johanna M. Levelt Sengers in a detailed study of thermodynamic properties of fluids near their critical points. The three scientists found that they could apply a scaled equation of state to carbon dioxide, xenon, and ^4He in the critical region, and that the results were consistent with several types of thermodynamic data.[137] In a placement that was perhaps not coincidental, the following paper in the same issue of the *Journal of Research,* written by Raymond Mountain, discussed a related topic—a dynamical model for the Brillouin-scattering spectrum of critical opalescence in carbon dioxide.

Several systems were investigated in the critical-point region by Sandra C. Greer in collaboration with Johanna Sengers, George T. Furukawa, and Robert Hocken during the early 1970s. These included thermodynamic anomalies in steam, heat capacity of argon-methane mixtures, and concentration gradients and thermal expansion in nitromethane-methylpentane mixtures.

In 1975, efforts to understand the behavior of gases near their critical points received a further boost from the work of Jan V. and Johanna M. H. L. Sengers. These scientists analyzed six fluids, using statistical methods: ^3He, ^4He, Xe, O_2, CO_2, and H_2O. They employed two scaled equations of state and confined their analysis to the critical region. They found that, within the limits of experimental accuracy, the two equations agreed with the data, lending credence to the idea that there existed a universality in critical behavior of gases.

Based upon their success, they offered parameters for 14 fluids in terms of a universal equation of state for the critical region.[138]

In a related study, Johanna Sengers provided historical insight on the development of the Van der Waals equation into a tool useful for modern scaling laws. Sengers described the features of Van der Waals' work that concerned critical phenomena, then traced the progress to the modern concepts of scaling and the universality of critical behavior in fluids.[139]

Johanna Sengers received the NBS Condon Award in 1975 and the Department of Commerce Gold Medal Award in 1978 for the quality of her work in thermodynamics.

Reaction Rate Constants

A study of the rates of reaction of methylene with carbon monoxide, oxygen, nitric oxide, and acetylene was completed by A. H. Laufer and Arnold M. Bass.[140] The experiments were accomplished by the use of flash photolysis of ketene in helium gas, with analysis of the reaction products performed in a gas chromatograph.

Both singlet and triplet methylene reactions were identified in the experiments. The rate constants ranged in magnitude from 10^{-11} cm^3 molecule^{-1} sec^{-1} to 10^{-15} cm^3 molecule^{-1} sec^{-1}.

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137 M. Vicentini-Missoni, J. M. H. Levelt Sengers, and M. S. Green, "Analysis of thermodynamic properties in the critical region of fluids," *J. Res. NBS* **73A**, No. 6, pp. 563-591 (1969).

138 J. M. H. L. Sengers and J. V. Sengers, "Universality of critical behavior in gases," *Phys. Rev.* **A12**, No. 6, 2622-2627 (1975).

139 J. M. H. L. Sengers, "From Van der Waals' equation to the scaling laws," *Physica* **73**, 73-106 (1974).

140 A. H. Laufer and A. M. Bass, "Rate constants for reactions of methylene with carbon monoxide, oxygen, nitric oxide, and acetylene," *J. Phys. Chem.* **78**, No. 14, 1344-1348 (1974).

Johanna M. H. L. Sengers adjusted the load on a piston gage which was used for accurate measurement of the pressure of gases used in her studies of critical phenomena.

Clinical Chemistry Standards

The development of a cholesterol Standard Reference Material (SRM 911) in 1967 marked the Bureau's entry into the field of clinical chemistry standards. The cholesterol SRM was followed quickly by others for urea (SRM 912), uric acid (SRM 913), creatinine (SRM 914), and calcium carbonate (SRM 915). These first contributions were made under the technical direction of Robert Schaffer, then chief of the Organic Chemistry Section of the Analytical Chemistry Division (ACD).

Sandra C. Greer mixed nitroethane and 3-methylpentane in a dry box as part of her research on critical phenomena in binary liquid mixtures.

In 1969, the Bureau signed an interagency agreement with the National Institutes of Health, Institute for General Medical Science. Under terms of the agreement, NIH would support ACD personnel in the development of additional clinical standards. More than two dozen standard chemicals, thermometers, and other apparatus were developed over a period of years under that program. Besides Schaffer, NBS scientists contributing to the project included William R. Shields, Bruce Coxon, Richard A. Durst, I. Lynus Barnes, Oscar Menis, John A. Simpson, Billy W. Mangum, Robert W. Burke, Radu Mavrodineanu, Rance A. Velapoldi, and Klaus D. Mielenz.

In 1971, International Federation of Clinical Chemistry officials asked NBS to assist in the development of clinical reference methods (RM). J. Paul Cali led the way to realization of this goal with an RM for measuring calcium levels in serum.

In 1974, Food and Drug Administration Bureau of Medical Devices managers initiated an interagency agreement for development of more RMs and for refinement of the isotope dilution mass spectrometry technique (IDMS) as a clinical tool to verify the accuracy of organic RMs. The IDMS method was used subsequently for cholesterol, glucose, urea, uric acid, creatinine, and triglycerides.

Robert Schaffer received the NBS Rosa Award in 1985 along with citations from the American Association for Clinical Chemistry for his contributions to the Bureau's clinical chemistry standards program.

The program remained as a fixture of NBS/NIST assistance to U.S. medical needs through the mid-1990s.[141]

Mathematics in Analytical Chemistry

An extensive bibliography containing nearly 600 references was compiled by Lloyd A. Currie, James J. Filliben, and James R. DeVoe on the use of mathematical and statistical methods used in analytical chemistry during the period 1967 to 1972.[142] Currie had a deep interest in the topic—he had written a definitive paper on the extraction of information from analytical chemistry experiments, proposing exact defining equations and formulas both for the general case and with specific application to radiochemistry investigations.[143]

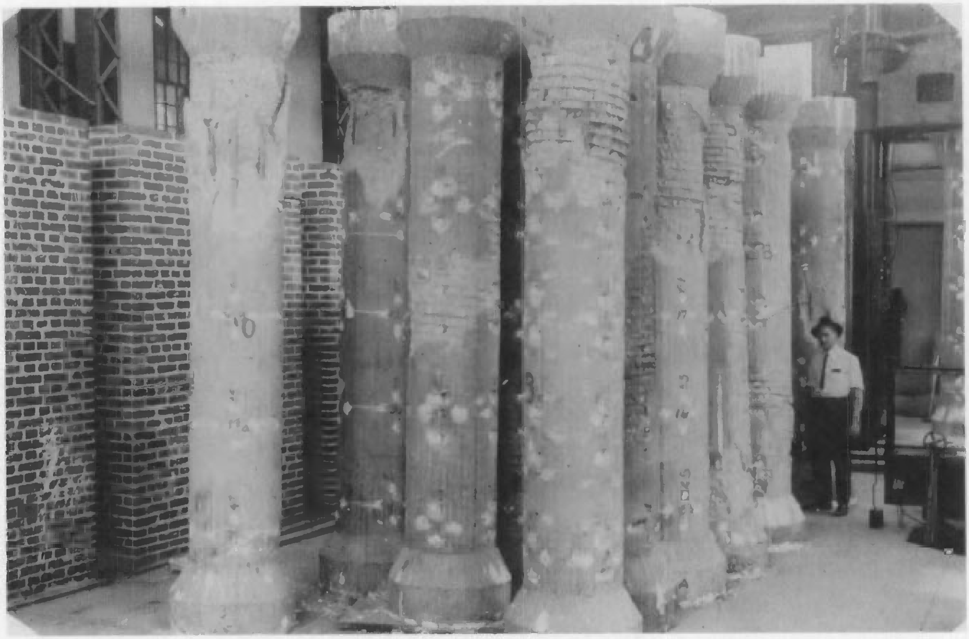
The bibliography was the result of a collaboration between the Analytical Chemistry Division and the Statistical Engineering Section of the Applied Mathematics Division. It covered several categories of publication:

- Reviews, conferences, journals, and books.
- Method characterization.
- Planning and optimization of experiments.
- Curve fitting.
- On-line computers.
- Specialized methods.

[141] Robert Schaffer, George N. Bowers, Jr. (Clinical Chemistry Laboratory, Hartford, Connecticut Hospital), and Robert S. Melville, (National Institutes of Health), "History of NIST's contributions to the development of Standard Reference Materials and Reference and Definitive Methods for clinical chemistry," *Clin. Chem.* **41**, No. 9, pp. 1306-1312 (1995).

[142] L. A. Currie, J. J. Filliben, and J. R. DeVoe, "Statistical and mathematical methods in analytical chemistry," *Anal. Chem. Ann. Rev.* **44**, 497R-512R (1972).

[143] Lloyd A. Currie, "Limits for qualitative detection and quantitative determination," *Analytical Chemistry* **40**, No. 3, March 1968, pp. 586-593.



Investigations for the building and construction industry began at the Bureau of Standards in the 1920s. In this 1920 photograph, brick piers and concrete columns were stress tested at the Bureau's Pittsburgh facility.

Building Science

It is fair to say that the Bureau of Standards has been studying problems connected with buildings and other structures since its founding in 1901. The acquisition of a 100,000 pound dead-weight tester in 1904 might be judged an official beginning, as might the formation of a Structural Materials Division around 1914, the creation of a Division of Building and Housing in 1921, or the first publication of Building Materials and Structures Reports in 1937.[144] No matter. Both the Congress and the Department of Commerce long understood that independent scientists and engineers could evaluate structures from informed and objective points of view, providing insights that could greatly improve America's construction industry.

Herbert Hoover, Secretary of Commerce from 1921-1928, established a Building Code Committee and a Division of Building and Housing within his department with the aim of stimulating the building industry. At the same time, a Research Associate program was initiated at NBS to encourage cooperation between the construction industry and Bureau scientists; the industry-sponsored associates took back to their companies a first-hand appreciation for the importance of laboratory-tested ideas for building, exerting a positive influence on the quality of building construction.[145]

[144] Cochrane, *Measures for Progress*, pp. 79, 131, 334.

[145] Paul R. Achenbach, "Building research at the National Bureau of Standards," *NBS Building Science Series 0*, October 1970, p. 6.

Initially fragmentary, contributions of NBS to the building industry became more cohesive in 1947 with the formation of the Building Technology Division under Douglas E. Parsons; sections included Structural Engineering, Fire Protection, Heating and Air Conditioning, Exterior and Interior Coverings, and Codes and Specifications. A. Allan Bates, James R. Wright, and Richard N. Wright (no relation to James) followed Parsons in leading the building science group as the organizational title changed over the years, but the group continued to focus on its central mission: to provide a sound base of data and analysis to undergird the U.S. construction industry.

A Center for Building Technology

With the beginning of Fiscal Year 1973 on July 1, 1972, Secretary of Commerce Peter G. Peterson directed that NBS should establish a Center for Building Technology (CBT). James R. Wright was chosen as the first Director of CBT. An advisory committee was formed to monitor its work. Three divisions were incorporated into the new center: Building Environment, Paul R. Achenbach, chief; Structures, Materials, and Life Safety, under William C. Cullen; and Technical Evaluation and Applications, headed by Harry E. Thompson. In addition, there were three offices: Building Standards and Codes Services, headed by Gene A. Rowland; Housing Technology, under Edward O. Pfrang; and Federal Building Technology, Sam Kramer, chief.

From 1966 to 1972, the full-time building research staff grew from 100 to 250. The growth was in part a response to the 1967 formation of the National Conference of States on Building Codes and Standards, and in part to the 1968 creation of an Office of Research and Technology in the Department of Housing and Urban Development, which in turn initiated *Project Breakthrough.*

In 1974, James Wright was chosen by director Richard Roberts as deputy director of the Institute for Applied Technology. Richard N. Wright was selected to succeed his namesake James as the second director of CBT. Richard Wright came to NBS from the University of Illinois in 1971. He served as chief of the Structures Section until he became center director. In that position, he led an NBS team to investigate earthquake damage to Managua, Nicaragua in 1972.

The Building Science Series

As noted in Chapter 1, a new series of NBS publications was begun in 1965 to take the place of the earlier *Building Materials and Structures Reports* as a convenient outlet for archival publications on the technology of building and as a means of centralizing the dissemination of information from the center. The new communication, with no fixed publishing schedule, was entitled the *Building Science Series.* The basic document in the series, written by Paul R. Achenbach and issued late in 1970, described the history of building research at NBS, the Bureau's contemporary program, and forecasts for the future.

Work of the New CBT

In part, changes in the scope of the Bureau's building-research program were brought about by the acquisition of new facilities on the Gaithersburg site. For example, the new structures laboratory allowed the group to supplement the usual testing machines with a reinforced, two-meter-thick tie-down floor and hydraulic actuators as a loading system that extended over an area 17 m on each side. Both fixed and cyclic loading could be applied, with forces varying in amplitude and frequency. Thirteen special-purpose environmental chambers—one large enough to accommodate an entire house—permitted tests ranging from air conditioning to thermal conductivity.

The range of activities undertaken by the building science group at NBS over the years was a broad one, as we shall demonstrate in the following paragraphs. Activities in fire research, long a part of the building research program, are discussed in a separate section.

- Computer models for the dynamic thermal performance of buildings were developed by Tamami Kusuda.[146] With the use of the large environmental chamber, predictions of the models could be compared with tests on full-scale houses under winter and summer weather cycles. As the models matured and confidence grew in their use, they became the basis for both commercial and Department of Energy designs for energy-efficient buildings.[147]

- Investigations at NBS into the inadequate performance and excessive failure of electric heat pumps, introduced in the early 1960s for family housing in the United States, revealed specific areas of failure and pointed the way to improved designs. As a result of the earlier work, reliable heat pumps were quickly made available when the energy crisis of 1973 prompted American builders to seek alternatives to electrical resistance heaters.

- An apparatus developed by Mahn H. Hahn, an *Industrial Research Associate,* was built to measure the dew point in sealed glass envelopes and thus to evaluate the moisture content in double-pane glass. The apparatus and its use became valuable assets to the construction industry.

- Thermal resistance of building insulation of various thickness could be measured with improved accuracy as a result of the development of a new line-source guarded hot-plate device. Henry E. Robinson, Mahn Hee Hahn, and Daniel R. Flynn designed the new instrument.[148]

[146] T. Kusuda, "Thermal response factors for multi-layer structures of various heat conduction systems," *ASHRAE Transactions* **75**, Part 1, pp. 246-271 (1969).

[147] T. Kusuda, "NBSLD, the computer program for heating and cooling loads in buildings," *NBS BSS 69,* 398 pp. July 1976.

[148] M. H. Hahn, H. E. Robinson, and D. R. Flynn, "Robinson line-heat-source guarded hot plate apparatus," *Amer. Soc. for Test. and Mat. Special Technical Publication* **STP 544** 1974, pp. 167-192.

Mahn Hee Hahn, Research Associate from the American Society for Testing and Materials, with the dew/frost point apparatus he developed to measure the moisture content of the air space in sealed insulating glass. The device received the IR-100 award from Industrial Research magazine as one of the most significant new technical products of 1975.

- In 1974 mobile homes accounted for 20 % of all new U.S. housing. To obtain uniform construction standards for safety, durability, and economy, the Department of Housing and Urban Development engaged NBS to define the problems to be addressed on these factors. William G. Street, William E. Greene, Jr., James H. Pielert, and Leopold F. Skoda undertook the study and prepared an *NBS Interagency Report*, number 75-690, in 1975.

- Collapse of the Skyline Plaza apartment complex on Mar 2, 1973, at Bailey's Crossroads in Fairfax, Virginia, caused the Occupational Safety and Health Administration to ask NBS to ascertain the nature of the failure and to address the general question of the adequacy of construction codes in multi-story buildings. The Bureau investigation, headed by Edgar V. Leyendecker and S. George Fattal, led to significant changes in construction codes pertaining to that incident. In addition, the work led to a long-term NBS program in non-destructive testing methods for ongoing construction.

- A flood in Fairbanks, Alaska in 1967 caused extensive damage to hundreds of homes. A visiting team of NBS engineers was able to recommend recovery procedures that minimized loss of property. The event triggered ideas for disaster mitigation at NBS and elsewhere. A 1972 workshop on building practices for disaster mitigation, held at NBS with the cooperation of the National Science Foundation, touched on problems caused by earthquake, wind, flood, and other dynamic hazards. Studies initiated as a result of the workshop[149] created the policy basis for the Earthquake Hazards Reduction Act of 1977 and a national program for earthquake hazard reduction in 1978. The Federal Emergency Management Agency, the U.S. Geological Survey, and the National Science Foundation joined NBS as lead agencies in the program.
- A new industry was established as a result of a 1975 NBS study of the premature failure of decking on highway bridges. Failure of the decks appeared to result from corrosion from deicing salts, which limited the useful life of the reinforcing bars to 5-10 years. A Bureau project conducted by James R. Clifton, Hugh F. Beeghly, and Robert G. Mathey identified several spray-applied powdered epoxy resins that gave promise of extending the service life of bridge decks to about 40 years.
- Lawrence W. Masters and his colleagues developed a systematic method in 1974 for predicting the service lives of building materials and other construction items that was used by the American Society for Testing and Materials as the basis for a new standard practice for accelerated testing.
- In 1973, NBS was asked to develop a technical basis for energy conservation in building construction. *NBSIR 74-452,* issued in 1974, contained an approach to the problem that was both technically and economically sound. Edited by James L. Heldenbrand, the document became the basis for a national consensus standard. Arthur D. Little Corporation estimated that use of the new approach would save nearly 50 % of the annual energy consumption for the average building.

Energy From Sunlight

One of the methods for energy conservation most often cited by environmentalists during the 1970s was solar power. The sun, they reasoned, offered free and reliable energy to Planet Earth every day; why not use it? Research projects to use sunlight for power blossomed immediately, their managers seeking methods and locations where solar power could provide a realistic source of energy to conserve increasingly expensive and polluting supplies of oil and coal.

NBS embarked on a program of developing standard test methods for solar energy collectors and thermal storage systems in the early 1970s under the leadership of James E. Hill. The work was initiated following a request from the National Science

[149] One of these was R. N. Wright, S. Kramer, and C. G. Culver, "Building practices for disaster mitigation," *NBS Building Science Series* **46**, 1973.

Foundation. Center for Building Technology staff purchased a factory-built four-bedroom house in 1972 and installed it in the center's large environmental chamber. There it was subjected to simulated summer and winter weather conditions while data were obtained on the interior response of the house to the heating and cooling loads. Then the house was moved to an outdoor site on the Gaithersburg grounds and tested under actual weather conditions.

During the latter part of 1974, a solar heating and cooling system was added to the house under the sponsorship of the Federal Energy Administration. Criteria for the new installation included the use of the forced-air distribution system that was already part of the house and installing only commercially available solar units that would satisfy at least 75 % of its energy needs. Installation and testing were supervised by James Hill and Thomas E. Richtmyer. Their report, published as *NBS Technical Note 892,* provided a complete discussion of the project, its successful results, and lessons learned.

The Federal Housing Administration of the Department of Housing and Urban Development led the way in many solar power projects. NBS was asked to participate in these projects as a result of the *Solar Heating and Cooling Demonstration Act of 1974.* The Bureau role was to develop guidelines for the evaluation of the economic performance of solar-energy heating and cooling systems, based on measurement data created or verified by NBS. In response to its new mandate, the Bureau asked its Center for Building Technology to formulate a plan to guide the development and implementation of standards for solar heating and cooling applications. The CBT plan was adopted by a committee of the American National Standards Institute, helping to coordinate industry and government efforts to utilize solar power. In the meantime, CBT engineers began to accumulate data to undergird the formulation of solar-power standards. With colleagues George E. Kelly and Tamami Kusuda, James Hill created protocols that led to national standards for solar-system evaluation.[150]

Rosalie T. Ruegg, an economist in the Center for Building Technology, led the way to the application of life-cycle cost analysis for solar systems.

By 1978, there were some 7 documents describing standards, codes, and performance criteria for solar energy systems.

Building Systems—A Performance Concept

The keynote for a new approach to building was struck during a 1968 Gaithersburg conference on *Performance of Buildings—Concept and Measurement.*[151] James R. Wright, then chief of the Building Research Division, stated:

> We have developed a definition for the performance concept and a set of five terms leading to a performance-type building code.

[150] See G. E. Kelly and J. E. Hill, "Method of testing for rating thermal storage devices based on thermal performance," *NBSIR 74-634* May, 1975, 45 pp. See also J. E. Hill and T. Kusuda, "Method of testing for rating solar collectors based on thermal performance," *NBSIR 74-635* December 1974, 63 pp.

[151] "Performance of Buildings—Concept and Measurement," *NBS Building Science Series 1,* W. W. Walton and B. C. Cadoff, editors, January 1970, 132 pp.

Solar collectors were installed in the National Bureau of Standards solar townhouse, a laboratory for a number of energy-conservation studies.

Wright drew upon the writing of John P. Eberhard to define the concept. The performance concept, wrote Eberhard, should begin with a statement of desired attributes of a material, component, or system in order to fulfill the requirements of the intended user. No instruction should be given as to the specific means to be employed in achieving the results.[152] Leading to the performance-based building code, he suggested, are performance requirements, performance criteria, evaluation techniques, performance specifications, and performance standards. Each of those terms could help to judge the adequacy of a given building technique to meet the actual needs of its occupants. This idea stood in sharp contrast to traditional building standards that prescribed materials and construction techniques.

In May 1972, the International Union of Testing and Research Laboratories for Materials and Structures teamed with the American Society for Testing and Materials and the International Council for Building Research Studies and Documentation to stage a symposium in Philadelphia devoted wholly to criteria for performance of

[152] J. P. Eberhard, "The performance concept: a study of its application to housing," *NBS Report No. 9849*, **1**, 47 (1968).

At left, NBS Institute for Applied Technology Director F. Karl Willenbrock and NBS Director Richard W. Roberts listened as Jim Hill of the Center for Building Technology (front right) described research at the NBS solar townhouse to Representatives George Brown of California and Don Fuqua of Florida. Behind them from the right were NBS Congressional Liaison Esther C. Cassidy, NBS Deputy Director Ernest Ambler, and Bill Wells of the House Science and Technology Committee staff.

buildings and their sub-systems. The editor of the proceedings, Bruce E. Foster, was on the staff of the Building Research Division. Many contributions to the symposium were offered by division staff members.[153] We note some of these here:

- Richard N. Wright, at that time still chief of the Structures Section, pointed out in a discussion presented jointly with A. H.-S. Ang from the University of Illinois the necessity of deciding how to prescribe performance criteria that were essential to human use of a building—for example, safety—without ignoring such problems as cost minimization.
- A general discussion of *Project Breakthrough,* initiated by the Department of Housing and Urban Development to solve the problem of creating 26 million new homes during the decade of the 1970s, was presented by Edgar V. Leyendecker. The project consisted of eight operational objectives:

[153] "Performance concept in buildings," Proceedings of a symposium, May 2-5, 1972, Philadelphia, Pennsylvania, *NBS Special Publication 361,* B. E. Foster, editor, 819 pp., February 1972.

1) Develop the means to increase housing production.
2) Modernize land-zoning regulations.
3) Develop performance criteria for building codes.
4) Upgrade the quality of professionals involved in the building industry.
5) Attract more skilled labor to the housing industry.
6) Encourage the development of new techniques and materials.
7) Encourage participation in housing modernization among state governments.
8) Encourage innovation in home financing.

- Norman F. Somes and Felix Y. Yokel discussed how testing procedures could be adapted to the performance concept in order to obtain realistic simulation of an actual structure without specifying the actual materials used in its construction. They suggested several useful criteria, including the selection of critical assemblies, critical loading conditions, critical environmental factors, and variability in performance.

- One problem associated with the new testing procedures was the paucity of performance data on conventionally constructed buildings. This topic was discussed by Somes and Yokel in collaboration with George C. Hsi and Hai S. Lew.

- An NBS computer program designed to augment standard industry procedures for calculating heating and cooling loads for buildings was described by Tamami Kusuda and Frank J. Powell. The program allowed the prediction of indoor temperatures from given values of air-conditioning and thermal insulation.

- Evaluation of the performance of structural building elements and interior-finish materials under fire conditions could be obtained from responses to low-intensity fires, according to Dan Gross and Jin Bao Fang. They recommended the use of burning wastebaskets or upholstered chairs to provide reproducible fire conditions.

- Another construction feature that needed attention in terms of performance evaluation was the response of structural adhesives to the effects of aging and environmental stresses. Thomas W. Reichard, Lawrence W. Masters, and J. H. Pielert classified the thousands of adhesives available to the industry into only three classes—those intended for use only during transport to the job site; those intended for long-term use, but not intended to carry structural loads; and those whose long-term strength was critical to the integrity of the building. The scientists prepared small test specimens of particular types of adhesives and subjected them, for example, to flexure tests after water submersion for one week. Such testing helped substantially in industry efforts to improve the performance of construction adhesives.

- Winthrop C. Wolfe made a similar contribution with regard to flooring finish, where the performance criteria included sanitation capability, solvent resistance, and wear characteristics.

Space Science

Bureau activities in space science during this period included astronomical studies, rocket technology, and scientific experiments in space. As is the case in many areas, NBS contributions in space science are mentioned in other sections as well.

Interstellar Species

Encouragement from David R. Lide, Jr., chief of the NBS Office of Standard Reference Data, helped to launch the Bureau into the identification of certain interesting interstellar species.

Lide assumed the leadership of the Office of Standard Reference Data early in 1969. He urged two staff members of his old section in the Optical Physics Division, Donald R. Johnson, a National Research Council-National Academy of Sciences postdoctoral research associate in 1967, and William H. Kirchhoff, a postdoctoral research associate in 1964, to evaluate the molecular spectroscopy literature for the benefit of scientists in the new field of radio astronomy. Since both scientists already had experience in that field, they happily pursued dual careers—critically examining data for the division's Molecular Spectroscopy Data Center part of the time, studying short-lived species in the laboratory and in outer space part of the time. Both activities were successful, soon involving, among others, Francis X. Powell and Frank J. Lovas, also of the Optical Physics Division.[154]

The group made many spectroscopic observations of short-lived reaction intermediates and other species of importance to radio astronomy and astrophysics, including the free radical OH, deuterated formyl ions, ethanol, sulfur dioxide, and dimethyl ether.[155]

Lovas and Johnson also were credited with helping Lewis Snyder of the Joint Institute for Laboratory Astrophysics and David Buhl of the Goddard Space Flight Center of NASA to identify maser emissions from red giant stars. Snyder and Buhl detected the signals late in 1973 in the Orion Nebula, using the 12 m radio telescope of the National Radio Astronomy Observatory. The nature of the radiation indicated the presence of maser action, but its complexity defied identification. Lovas and Johnson, however, were able to identify the signals as originating from vibrational excitation in SiO. Their identification was later confirmed by other astronomers.[156]

[154] F. X. Powell and D. R. Johnson, "Microwave detection of $H_2{}^{18}O$," *Phys. Rev. Lett.* **24**, No. 12, 637 (1970). See also D. R. Johnson, F. J. Lovas, and W. H. Kirchhoff, "Microwave spectra of molecules of astrophysical interest. I. Formaldehyde, formamide, and thioformaldehyde," *J. Phys. Chem. Ref. Data* **1**, No. 4, 1011-1046 (1972).

[155] D. R. Johnson and F. J. Lovas, "A new look at the laboratory microwave spectrum of cyanoacetylene," *Astrophys. J.* **169**, 617-619 (1971). See also D. R. Johnson and F. J. Lovas, "Microwave detection of the molecular transient methyleneamine ($CH_2 = NH$)," *Chem. Phys. Lett.* **15**, No. 1., 65-68 (1972). See also L. E. Snyder, J. M. Hollis, B. L. Ulich, F. J. Lovas, and D. R. Johnson, "Radio detection of interstellar sulfur dioxide," *Astrophys. J.* **198**, No. 2, L81-L84 (1975).

[156] Barbara G. Levi, "Silicon-monoxide masers show up in infrared stars," *Physics Today* pp. 17, 20, November 1974.

Their work was significant for scientists in fields as disparate as astrophysics and air pollution. Johnson and Lovas were jointly awarded the Department of Commerce Gold Medal in 1977.

Stellar Modeling

T. R. Ayres and Jesse L. Linsky constructed models for the star Arcturus, based upon spectral observations of ionized calcium and magnesium. The models separately considered the upper photosphere and chromosphere. They also studied the formation of a particular member of the Balmer series, Hϵ, in the sun and in Arcturus as part of their continuing work on stellar chromospheres.[157]

In collaboration with G. H. Mount, Linsky also suggested that the sun may contain a significantly lower carbon abundance than previously thought. The two physicists reached this conclusion on the basis of a detailed study of the spectra of solar CN, in which they assumed an absence of local thermodynamic equilibrium. The new estimate affected other astrophysical calculations.[158]

David G. Hummer and P. B. Kunasz offered two contributions to the study of radiative transfer in stellar matter during this period. In papers published in the *Monthly Notices of the Royal Astronomical Society,* they considered the fundamentals of line formation in extended spherical atmospheres whose constitutive properties depended on radius in an arbitrary way. Their study prompted them to propose a numerical solution to the line-transfer problem in spherically symmetric atmospheres.[159]

Hummer and D. Mihalas analyzed the spectrum of nitrogen III in celestial bodies known as O stars on the basis of a detailed solution to the coupled statistical-equilibrium and transfer equations for a multi-line, multilevel, multi-ion ensemble. Their results, indicating that N III lines could be produced in static, non-extended atmospheres in radiative equilibrium, provided evidence that the presence of emission lines in a spectrum was not in itself proof for the existence of a stellar chromosphere.[160]

Along with G. B. Rybicki, Hummer provided an extended discussion of the formation of spectral lines in optically thick systems for the journal *Annual Reviews of Astronomy and Astrophysics.* [161]

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[157] T. R. Ayres and J. L. Linsky, "Stellar model chromospheres. III. Arcturus (K2 III)," *Astrophys. J.* **200**, No. 3, pp. 660-674 (1975); same authors, "Stellar model chromospheres. IV. The formation of the Hϵ feature in the sun (G2 V) and Arcturus (K2 III)," *Astrophys. J.* **201**, No. 1, pp. 212-221 (1975).

[158] G. H. Mount and J. L. Linsky, "A new solar carbon abundance based on non-LTE CN molecular spectra," *Astrophys. J.* **202**, No. 1, L51-L54 (1975).

[159] P. B. Kunasz and D. G. Hummer, "Radiative transfer in spherically symmetric systems. III. Fundamentals of line formation," *Mon. Notic. Roy. Astron. Soc.* **166**, No. 1, 19-55 (1974). Also, same authors, "Radiative transfer in spherically symmetric systems. IV. Solution of the line transfer problem with radial velocity fields," *Mon. Notic. Roy. Astron. Soc.* **166**, No. 1, 57-78 (1974).

[160] D. Mihalas and D. G. Hummer, "Analysis of light-ion spectra in stellar atmospheres. III. Nitrogen III in the O stars," *Astrophys. J.* **179**, No. 3, 827-845 (1973).

[161] D. G. Hummer and G. B. Rybicki, "The formation of spectral lines," Chapter in *Annual Reviews of Astronomy and Astrophysics,* **9**, 237-270, 1971.

In recognition of the quality of his scientific leadership in stellar radiative transfer, Hummer became the 13th NBS staff member to win the Arthur S. Flemming award.

Rocket Technology

Certain thermodynamic properties of molybdenum, graphite, MoF_5, and niobium were measured, others were calculated from models by Thomas B. Douglas and Charles W. Beckett to complete data sets on materials important to rocket technology. For Mo, accurate enthalpy measurements in the temperature range 273 K to 1170 K were coupled with data obtained earlier at NBS to complete a set of thermodynamic functions for that element from 273 K to 2100 K. Fast-pulse heat-capacity data, believed accurate within 3 %, were obtained on graphite over the range 1500 K to 3000 K. Change in the normal spectral emittance and sample radiance near the melting temperature of niobium were observed using the pulsed technique as well.[162]

The sub-second pulse method, employed with great effectiveness by Cezairliyan in work described in Ch. 2, was used also to obtain information on the specific heat, electrical resistivity, and hemispherical total emittance for iron and a niobium-tantalum-tungsten alloy in the range 1500 K to 2800 K. A solid-solid transformation (gamma iron to delta iron) was detected in each of the different types of measurement, demonstrating the feasibility of fast phase-transition observations.[163]

Consumer Protection

In a sense, all NBS work protected the consumer—his person, his pocketbook, or the quality of his technical information and products. In this section, however, we highlight studies applicable directly to medicine, environmental protection, and equity in trade.

Materials for Prosthetic Devices

The successful use of metals for prosthetic devices depended upon three properties—"biocompatibility," adequate mechanical properties, and high corrosion resistance.[164] Anna Fraker, newly arrived at NBS in 1967 as a young postdoctoral research associate, joined J. R. Parsons, a Presidential Intern, and NBS scientists M. P. Yeager, J. A. S. Green, Cletus J. Bechtold, and Arthur W. Ruff, former chief of the Metallurgy Division, in a long-term study of prosthetic metals. In their investigations, they collaborated with many groups outside NBS to evaluate candidate metals.

[162] T. B. Douglas and C. W. Beckett, "Thermodynamics of chemical species important to rocket technology," *NBSIR 73-280,* 109 pp., January 1973.

[163] T. B. Douglas and C. W. Beckett, "Thermodynamics of chemical species important to rocket technology," *NBSIR 73-281,* 122 pp., July 1973.

[164] See, for example, Anna C. Fraker and A. W. Ruff, "Metallic surgical implants: state of the art," *J. Metals* **29**, No. 5, pp. 22-28 (1977).

Among the most promising metals tested were stainless steel, cobalt alloys, and titanium.[165] Utilized by the aerospace industry for its strength and moderate density, titanium won a high place among prosthetic metals for its resistance to corrosion by bodily tissues and fluids. The Bureau metallurgists expanded the store of knowledge on the suitability of titanium and other prospective implant materials through studies of microstructures, surface properties, and reactions with physiological solutions such as salines, uric acids, and amino acids.

They found that titanium typically formed a tough oxide surface film that resisted attack by biological materials. They also investigated a variety of titanium alloys involving aluminum, vanadium, and palladium. An interesting feature of the study was the indication that certain crystalline orientations showed reduced susceptibility to chemical attack.[166]

Tumor Detection—the Birth of a New Medical Technique

Non-invasive detection of malignancies in patients was a long-time goal of the medical community. NBS scientists, no less eager than physicians to ease human suffering, glimpsed a possibility that led to the medical specialty that came to be known as *Magnetic Resonance Imaging.*

Irwin D. Weisman and Lawrence H. Bennett of NBS, Louis R. Maxwell, Sr., a retired government scientist, and Mark W. Woods and Dean Burk of the National Cancer Institute knew that differences between normal tissue and tumorous tissue had been detected in laboratory samples by measuring their proton nuclear spin-lattice relaxation times. Why not, they thought, use their specialty, pulsed nuclear magnetic resonance, on living subjects? That technique would give a measure of tissue relaxation times. If the experiment worked, it would open the possibility of quick, non-invasive cancer detection.

To test their idea, the group enlisted several mice whose tails became test samples. The scientists transplanted malignant melanoma tumors onto the mouse tails, splinted them to reduce movement, and placed them within a resonance probe coil anchored between the poles of a powerful electromagnet. Success! The mice appeared to be unharmed by the test procedure, and the researchers found an easily detectable difference in spin-lattice relaxation time (0.7 s vs 0.3 s for normal tissue).

Plenty of details remained to be worked out before the new technique would become a routine—though expensive—medical diagnostic procedure for the detection of many types of abnormal tissue in patients throughout the world. But the authors saw the future clearly in their first report on the experiments:

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[165] J. R. Parsons and A. W. Ruff, "Survey on metallic implant materials," *NBSIR 73-420,* December 1973, 55 pp.

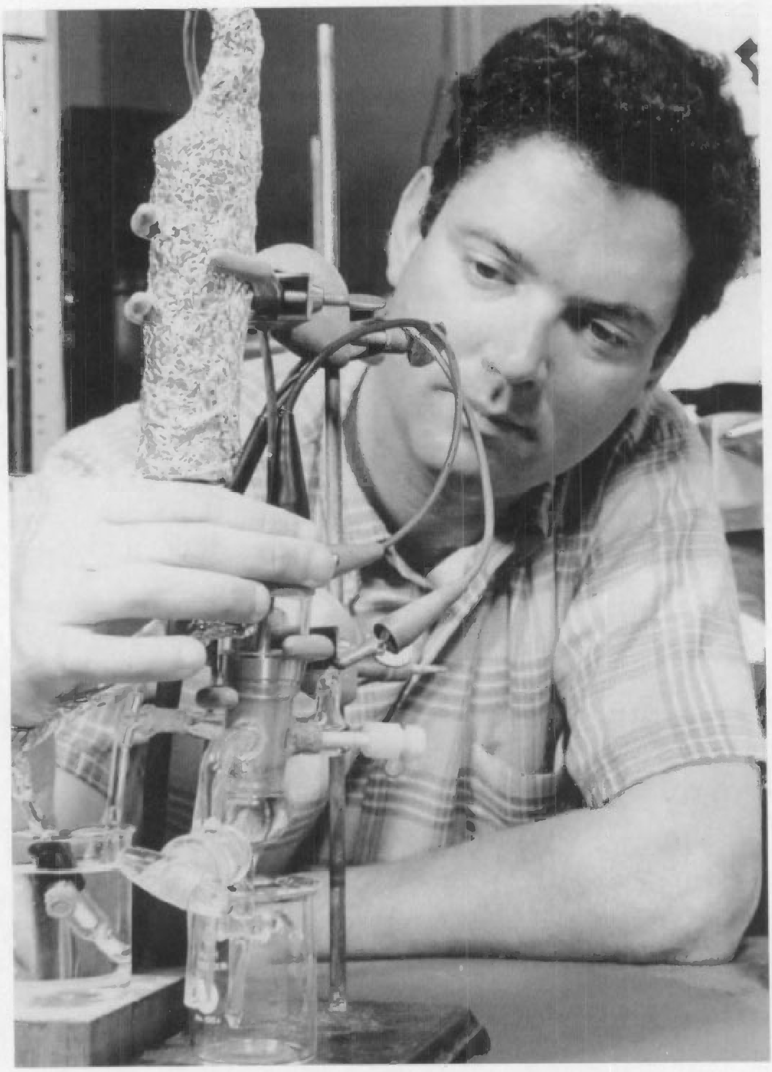
[166] A. W. Ruff and A. C. Fraker, "Investigation of the anisotropic anodic polarization behavior of titanium," *Corrosion* **30**, No. 7, pp. 259-264 (1974).

NBS metallurgist Anna C. Fraker showed school children an x ray of a surgically implanted artificial hip joint.

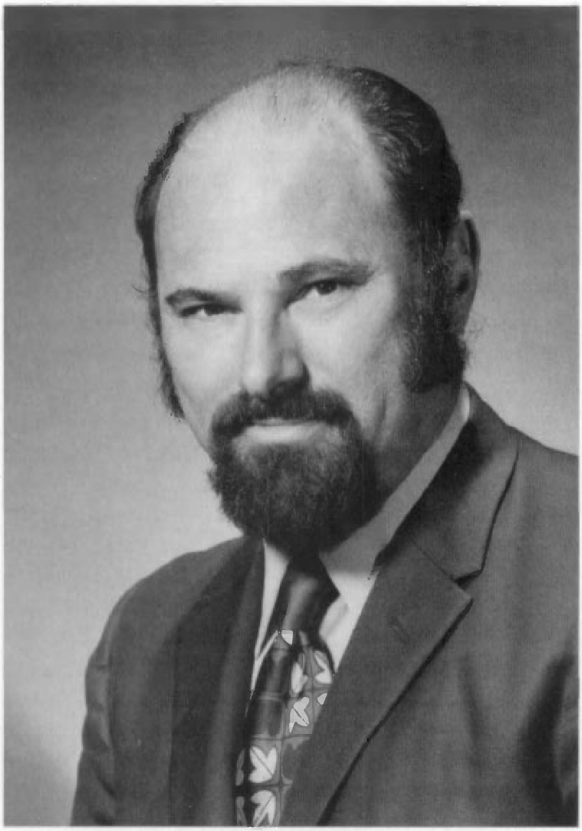
> We have been able to detect and monitor the growth of a cancer (a transplanted S91 melanoma) in a live animal, using pulsed NMR. Our results suggest that it would be worthwhile to attempt to develop this technique for the detection and monitoring of tumors in humans. Perhaps NMR could take its place beside thermography or radiography as a nonsurgical technique for cancer detection and analysis of cancer growth rate.[167]

The concept embodied in the discovery by the five-man group generated considerable excitement. About 600 requests were received for reprints of their report. The idea was quickly seized for use in non-invasive medical diagnostics. Renamed *Magnetic Resonance Imaging* (MRI) to avoid the frightening word "nuclear," the technique blossomed into a medical specialty. A technical display created by the American Museum of American History bears a caption that reads, in part, "The clarity of the images produced by magnetic resonance imaging far surpasses that of conventional x rays and rivals those of CAT scans. In addition, this technology allows investigators to monitor and study chemical changes in live tissue on a molecular level without intruding into the body." The display gave credit to the Bureau scientists for their seminal role in MRI development.

[167] Irwin D. Weisman, Lawrence H. Bennett, Louis R. Maxwell, Sr., Mark W. Woods, and Dean Burk, "Recognition of cancer in vivo by nuclear magnetic resonance," *Science* **178**, pp. 1288-90 (Dec 22, 1972).



NBS chemist John R. Ambrose developed tests to predict how surgically implanted materials would react to bodily tissues and fluids. In this photograph, Ambrose worked on a laboratory method that simulated crevice-corrosion in the body.



Lawrence H. Bennett joined NBS after receiving the Ph. D. degree in physics from Rutgers, the State University of New Jersey, in 1958. Among his research interests was the electronic properties of metals and alloys, for which he received the Department of Commerce Gold Medal Award in 1971.

Sniffing Out Pollutants

A small group of scientists in the Optical Physics Division—Arthur G. Maki, W. Bruce Olson, and A. Kaldor—and their colleagues A. J. Dorney and I. M. Mills from the university at Reading, England made a study of the detection of pollutants by optical means. They developed a technique for the detection of nitric oxide emanations from sources such as internal combustion engines and smokestacks, based upon the use of a relatively inexpensive system involving lasers and magnets.

Using the Zeeman effect, which enabled the resonant frequency of an optical transition to be magnetically shifted to a different value, they could detect airborne NO at the level of 3 parts per million.[168] A major air pollutant, NO produced smog and human discomfort, including eye irritation.

The group also resolved an uncertainty affecting the detectability of sulfur trioxide, a pollutant found in acid rain. Performing two different optical experiments and a band calculation, they were able to remove an ambiguity in the assignment of the frequencies of two of the Raman-active infrared lines of the SO_3 molecule.[169]

[168] A. Kaldor, W. B. Olson, and A. G. Maki, "Pollution monitor for nitric oxide: a laser device based on the Zeeman modulation of absorption," *Science* **176**, No. 4034, p. 508 (May 5, 1972).

[169] A. Kaldor, A. G. Maki, A. J. Dorney, and I. M. Mills, "The assignment of ν_2 and ν_4 of SO_3," *J. Mol. Spectrosc.* **45**, No. 2, 247-252 (1973).

Sizing Aerosols With Lasers

Cary Gravatt, a Polymers Division physicist, developed a method for the determination of the size distribution of particulate matter in air.

In the technique, air carrying the particles was blown through a continuous-wave laser beam. Light scattered from the particles was collected by separate annular fiber-optic rings set at slight angles to the laser axis. The fiber optics carried the scattering signals to photomultiplier tube detectors. Analysis of the signals from two rings yielded estimates of the diameter of each particle, irrespective of the index of refraction of the particle. By varying the angles of the observing rings, Gravatt could preferentially search for particles of various sizes.

Besides the particle sizes, the apparatus also yielded information on the chemical natures of the particles and on their concentrations.

The new instrument found application in monitoring all types of aerosols, from dust in homes, factories, and coal mines to clouds, fuels, paint sprays, and smokestack emissions.[170]

Honest Measure for Natural Gas

Increased use of liquefaction to facilitate trade in natural gas involved the Cryogenics Division in an investigation of the density of that valuable energy source.

Shipping large quantities of natural gas from the remote sites where it was often found was prohibitively expensive until techniques were developed to transport the product—mostly methane, but with variable fractions of nitrogen, ethane, propane, and butane—in liquid form. Monster tanker ships were built to carry the product to user markets, keeping the liquefied gas below its boiling temperature near 120 K (about −250 °F).

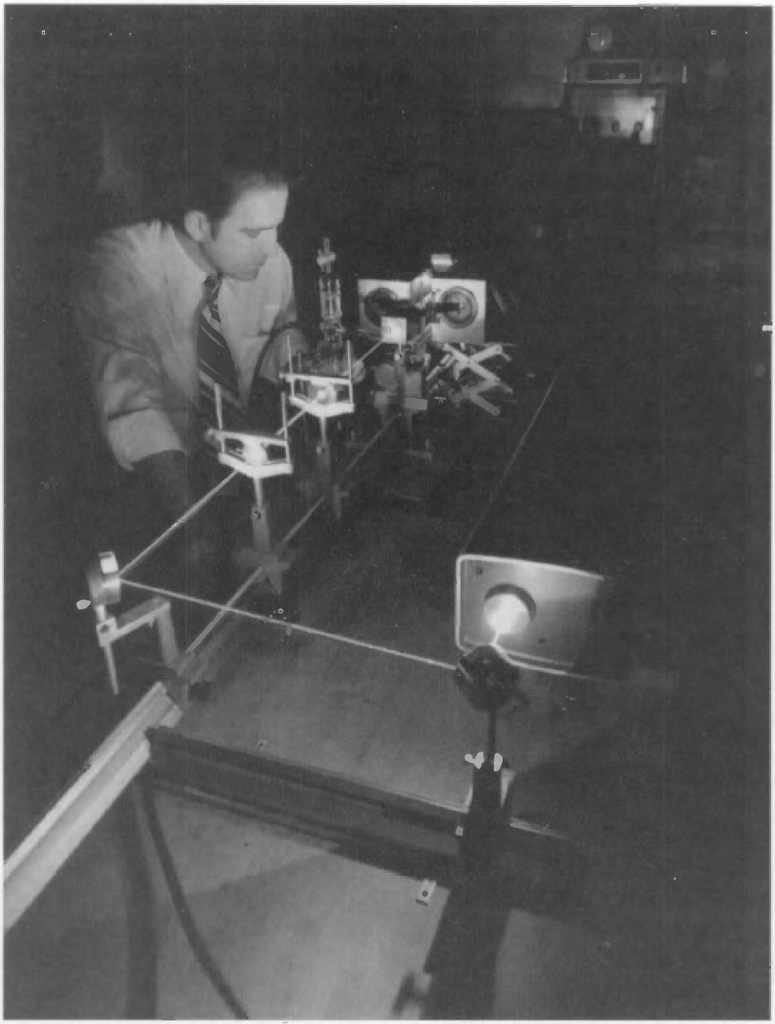
Trouble came when the buyers and sellers realized that during the long trek to the user, part of the liquefied gas evaporated, so that the assay performed prior to loading was no longer valid.

A consortium of 10 energy companies came to NBS, asking the Bureau to measure the densities of various mixtures of the components of natural gas to help buyer and seller agree on a reasonable value for a given shipment.[171]

By mid-1974, B. A. Younglove, physicist in the Cryogenics Division, was able to report the results of a whole series of measurements on methane. He measured the specific heat of saturated liquid methane at 66 temperatures over the range 95 K to 187 K and calculated the specific heat at constant volume at 20 densities ranging from 0.8 of the critical density to 2.8 times the critical density, for the temperature range

[170] C. C. Gravatt, Jr., "Real time measurement of the size distribution of particulate matter by a light scattering method," *J. Air Poll. Control Assn.* **23**, No. 12, 1035-1038 (1973). See also *NBS Technical News Bulletin,* December 1972 pp. 276-277.

[171] "Research grant for LNG study," *Tech. News Bull.*, November 1972, p. 259.



Cary Gravatt of the NBS Polymers Division positioned a device that blew a jet of dust-laden air across a laser beam. The particle size distribution was determined in real time by measuring the ratio of the amount of light scattered at two angles. Gravatt developed the apparatus as part of the NBS Measures for Air Quality Program which provided technical support for the U. S. Environmental Protection Agency.

from 91 K to 300 K.[172] These were the most comprehensive measurements made until that time on compressed liquid methane. The uncertainty level, below 0.5 %, was sufficiently small to permit use of the data for thermodynamic calculations needed by producers and shippers of liquefied natural gas.

[172] B. A. Younglove, "The specific heats, C_σ, and C_v, of compressed and liquefied methane," *J. Res. NBS* **78A**, No. 3, 401-410 (1974).

R. D. Goodwin assisted in the work by calculating a comprehensive set of thermophysical properties for methane over the temperature range from 90 K to 500 K and for pressures up to 700 times atmospheric pressure. In computing his results, Goodwin used a new equation of state. He based his calculations mostly on ideal-gas specific heats and on experimental pressure-density-temperature relations.

Emphasizing the importance of accurate information on the properties of methane for the design engineer, Goodwin made use of a great deal of existing experimental data, including that provided by Younglove, to evaluate his results. He found substantial variation in existing heat-of-vaporization data, but found agreement with one set of data within about 2 %. His heat capacity calculations agreed with the measured values of Younglove within about 2 % over the region of overlap, as well.[173]

What a Noise!

Everyone knew that big trucks could be extremely loud. The interesting question was: how loud? In cooperation with the U.S. Department of Transportation and the American Trucking Association, NBS scientists measured the noise levels of trucks. They used a research runway operated by the National Aeronautics and Space Administration at Wallops Island, Virginia. Thirteen diesel tractor-trailer combinations and a gasoline-powered delivery van were tested by William A. Leasure, Jr., Thomas L. Quindry, Denzil E. Mathews, and James M. Heinen.[174]

Measurements were taken using microphones located 15 cm from each ear of the truck driver. At the same time, exterior measurements were made by a series of microphones that heard pretty much what other drivers or residents along the road would have heard. Both stationary and moving measurements were performed. The results indicated that, indeed, trucks can be loud (75 dB to 95 dB). The Occupational Safety and Health Administration recommended an eight-hour-per-day noise limit of 90 dB to avoid permanent hearing loss.

Other loud sounds were evaluated as well, including the firing of pistols and rifles.

It was only a small paradox that the anechoic chamber in the Sound Building— without doubt the quietest place at the Bureau— was a focal point for laboratory experiments on other types of noise. One of several experimental rooms in the building, the anechoic chamber achieved its quiet because it was lined with large fiberglass wedges paired in a pattern that absorbed more than 99 % of the sound originating within it.

One of the studies conducted in the anechoic room during Roberts' tenure was a series of hearing aid investigations, conducted for such sponsors as the Veterans Administration. The quality of microphones, loudspeakers, and other audio equipment was evaluated as well.

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[173] R. D. Goodwin, "The thermophysical properties of methane, from 90 to 500 K at pressures to 700 bar," *NBS Technical Note 653,* 274 pp., April 1974.

[174] W. A. Leasure, Jr., T. L. Quindry, D. E. Mathews, and J. M. Heinen, "Interior/exterior noise levels of over-the-road trucks," *NBS Tech. Note 737,* 314 pp., September 1972. See also *NBS Tech. News Bull.,* February 1973, pp. 32-33.

Physicist Michael T. Kobal of the NBS Sound Section developed a test to evaluate the effectiveness of hearing protectors used on firing ranges.

An anthropomorphic mannequin used for acoustic research at NBS "listened" through an over-the-ear hearing aid in an anechoic chamber as part of a testing program conducted for the Veterans Administration. Martin Bassin positioned the sound source.

In March 1976, the Juilliard String Quartet tested the acoustical properties of their rare 17th and 18th century instruments in the NBS anechoic chamber against those of a matched set of new instruments made by Massachusetts instrument maker Marten Cornelissen. During the same visit, the quartet treated the Gaithersburg staff to an open rehearsal in the Green Auditorium.

In striking contrast to the anechoic chamber, the walls of a reverberation chamber, made of concrete, reflected about 95 % of sound striking them. The acoustic absorption of architectural materials was evaluated there, as was the intensity of sound emitted by machinery.

A third Sound-Building facility, containing small, insulated listening booths, was used for noise-annoyance studies by—among others—John A. Molino. In one such study, student-age subjects could reduce the intensity of sound they heard through earphones by tapping more frequently on a telegraph key. The attention of the subjects was focused on a reading task, the announced goal of their participation in the experiments. Molino sought in the experiments to develop an "aversion" method for evaluating human distaste for a variety of sounds, from pure tones to "white noise."[175]

[175] J. A. Molino, "Measuring human aversion to sound without verbal descriptors," *Percept. Psychophys.* **16**, No. 2, 303-308 (1974).

The NBS Sound Section conducted experiments to rate sounds according to their "loudness," "annoyance," and "unpleasantness" in an effort to find an objective basis for product standards and rational urban planning. In this photograph, a subject heard varying types and intensities of sound. She could diminish uncomfortable sound levels by pressing the response key.

Building Better Incinerators

How could NBS help municipalities to better dispose of their combustible waste? That was the question asked by the American Society of Mechanical Engineers (ASME).[176] It was not a trivial question, since the "typical" municipal waste stream was anything but uniform. The incinerator engineer needed to know what materials might be found in the waste stream, and what might be the consequences of burning

[176] "NBS helps with problems of waste incineration," *NBS Tech. News Bull.*, February 1973, p. 42.

the stuff. He did not want to produce poisonous effluent. He needed to monitor and, if possible, to regulate the combustion temperature to obtain optimal results.

The Bureau, it seemed, could help in two ways. One way was to actually burn statistically selected samples of trash to evaluate the range of combustion temperatures and products, and this type of combustion experiment was performed at NBS by a group that included Martin L. Reilly and Kenneth Churney. Another method was to provide data on heats of formation for the most common waste materials in a form that combustion engineers would find usable. This task was accomplished by NBS chemists George T. Armstrong and Eugene S. Domalski in collaboration with colleagues from the ASME.

Armstrong, Domalski, and their co-workers compiled thermodynamic data needed by waste-incinerator engineers for more than 1300 substances. Included in the compilation were the following:

- Heats of combustion and formation for 719 organic compounds containing the elements C, H, N, O, P, or S.
- Thermodynamic property values for organic halogen compounds, organometallics, and metal salts of organic acids, tabulated in the *NBS Technical Note 270* series by Donald D. Wagman, William H. Evans, and Vivian B. Parker.
- Data on certain hydrocarbons, treated by Frederick D. Rossini. The needed information was published in book form by the ASME.[177]

Meeting the Energy Crisis

As observed earlier in this chapter (see A Crisis in Energy), energy based on the consumption of oil reached premium prices during this period as most of the world's major oil-producing countries discovered the political and economic leverage inherent in restricting oil sales. Efforts at NBS to mitigate the energy crisis took several forms—turning down the office thermostats in winter, measuring thermal conductivity of insulation materials, studying alternative energy sources, and evaluating the rate of energy consumption of popular appliances, to name a few. Some of these types of projects are noted in this section.

Meeting the Energy Crisis in Housing, Travel, and Business

The Building Research Division staff was busy with energy-conservation projects during the Nixon administration, although the division continued to work on a great variety of other problems as well. The rapidly rising cost of oil—source of much of America's power—gave new impetus to efforts to maximize the efficiency with which energy was used.

[177] *Combustion Fundamentals for Waste Incineration,* S. R. Beitler, G. T. Armstrong, E. S. Domalski, and T. R. Keane, editors (New York, NY: The American Society of Mechanical Engineers, 1974) 217 pp.

In 1975, NBS invited a group of consumers from Montgomery County, Maryland to provide their reactions to three proposed energy guide labels for home laundry equipment.

As early as 1970, Jersey City, New Jersey, had been selected as a demonstration site for improved housing construction as part of *Project Breakthrough,* an initiative of the Department of Housing and Urban Development. One of the first Bureau contributions to the program, involving Jack E. Snell and Paul R. Achenbach, was the identification of operating and performance data on the total consumption and distribution of energy on the site as a precursor to utilizing energy in an effective manner.[178] Such features as the design and use of appliances, heating and ventilating equipment, and power distribution equipment were considered in the study. Later, in 1974, Snell was selected to head the newly created Office of Energy Conservation, located in the Center for Building Technology.

A detailed examination of one portion of the energy-conservation program—maximizing dollar savings over the life of residential heating and cooling equipment—was treated by Stephen R. Petersen. He discussed the economics of modifying insulation and installing storm windows and doors in terms of the climate, fuel costs, and materials costs at the location of the residence under study.[179]

[178] J. E. Snell and P. R. Achenbach, "Total energy systems: A review of recent NBS activities," *Proc. Effective Energy Utilization Symp., Drexel University, Philadelphia, Pa.,* June 8-9, 1972, pp. 201-233.

[179] S. R. Petersen, "Retrofitting existing housing for energy conservation," *NBS Building Science Series* 64, December 1974, 76 pp.

Making the Most of Your Energy Dollars was published in 1975 by the National Bureau of Standards and the Federal Energy Administration. It provided guidelines to homeowners in determining the most cost-effective energy improvements for their homes.

In another energy-conservation study, David M. Levinsohn and James T. McQueen estimated the fuel consumption of automobiles in terms of the types of vehicles and the characteristics of the roadways involved. They considered the use of expressways, arterial roads, and local streets, with the fuel consumption varying according to operating conditions. The authors expressed the belief that such basic data could be used by urban planners to design transportation grids for maximum energy conservation.[180]

Yet another contribution from the Bureau took the form of a handbook, *Energy Conservation Program Guide for Industry and Commerce (EPIC)*. It was written by Robert R. Gatts, Robert G. Massey, and John C. Robertson to suggest specific techniques by which businesses could economize on their use of energy while still meeting their organizational goals.[181]

The result of a collaboration between NBS and the Federal Energy Administration, EPIC was a guide to energy conservation that became a university text. It offered details of methods that could be used to inaugurate programs in energy conservation, as well as more than 200 suggestions for saving energy. Each of the one-sentence

[180] D. M. Levinsohn and J. T. McQueen, "A procedure for estimating automobile fuel consumption on congested urban roads," *NBSIR 74-595*, August 1974, 20 pp.

[181] R. R. Gatts, R. G. Massey, and J. C. Robertson, "Energy Conservation Program Guide for Industry and Commerce," *NBS Handbook 115*, September 1974, 212 pp.

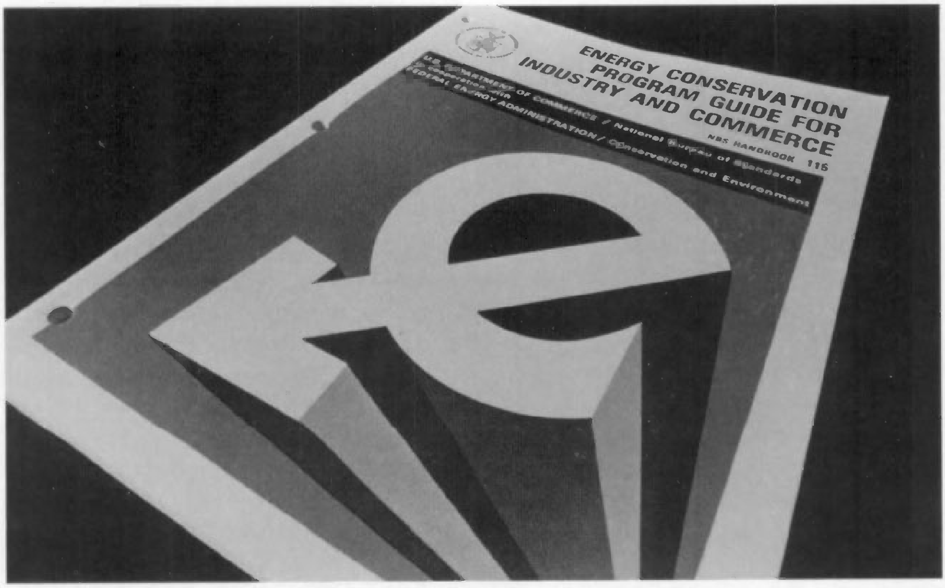
suggestions was labeled an *Energy Conservation Opportunity.* Actual case histories illustrated the ideas, which encompassed—among others—minimizing the expenditure of electrical power, processing energy, and energy use in the handling of materials.

The guide also provided useful methods for calculating the energy savings realized in particular cases. Organizations were listed from which information could be obtained on conservation projects, too. The original cost of the guide was less than $3.

One of the first college courses to make use of the new guide was offered by the School of Continuing Education of the University of Pittsburgh. It was known as the *Energy Management for Industry and Commerce course.* Instructors in the course often obtained advice on presenting the material from the NBS Office of Energy Conservation.[182]

Supplements to update the EPIC guide were issued over a period of several years.

An Office of Housing Technology (OHT) was established at NBS in 1972 under the leadership of Edward O. Pfrang, James G. Gross, and Joseph Greenberg. By August of that year, the office was involved in several projects. These included



In 1975 NBS published the *Energy Conservation Program Guide for Industry and Commerce.* The guide gave specific practical hints and case studies on energy-saving for small and medium-sized companies as well as for corporate giants.

[182] "An EPIC undertaking: out of the classroom, into the plant," *NBS Dimensions,* January 1976, pp. 6-9.

Project Feedback, an attempt to evaluate consumer reaction to housing innovations developed in *Operation Breakthrough;* an energy-conservation program associated with the Jersey City, New Jersey, Breakthrough site; and a project assessing the dangers to children from lead-based paint.[183]

In *Project Feedback,* consumer reactions were obtained directly by interviews with citizen residents of the modernized housing. The energy-conservation project produced data on the efficiency of utilization of waste heat—generated as a by-product of electric power production—for residential heating, cooling, and hot-water production. The lead-paint project involved detection methods for the offending paint and the development of methods for the removal of the paint or otherwise eliminating the danger to children from the paint.

Preventing Electrical Blackouts

The transmission of large quantities of electrical power could be adversely affected by transient currents on the lines, in worst cases causing power blackouts. Shunt reactors, large devices similar to transformers, could "tune out" such transients, thus stabilizing power transmission. Accurate measurement of power losses arising from the use of shunt reactors, however, was a problem for electric utilities. It was solved by Oskars Peterson, chief of the High Voltage Measurements Section of the Electricity Division, along with his colleagues Walter J. Mangan, Ronald Stanley, and William E. Anderson—a Presidential Intern from the University of Missouri. These scientists developed a self-balancing high voltage capacitance bridge which was a key component of the solution.[184]

Used with appropriate auxiliary equipment, the new bridge provided accurate measurements of the power losses accompanying the installation of high-voltage shunt reactors, even though the losses engendered by the highly efficient reactors were so small that they were difficult or impossible to measure by conventional means.

The new bridge also permitted the initiation of a new NBS calibration service for large capacitors and shunt reactors.

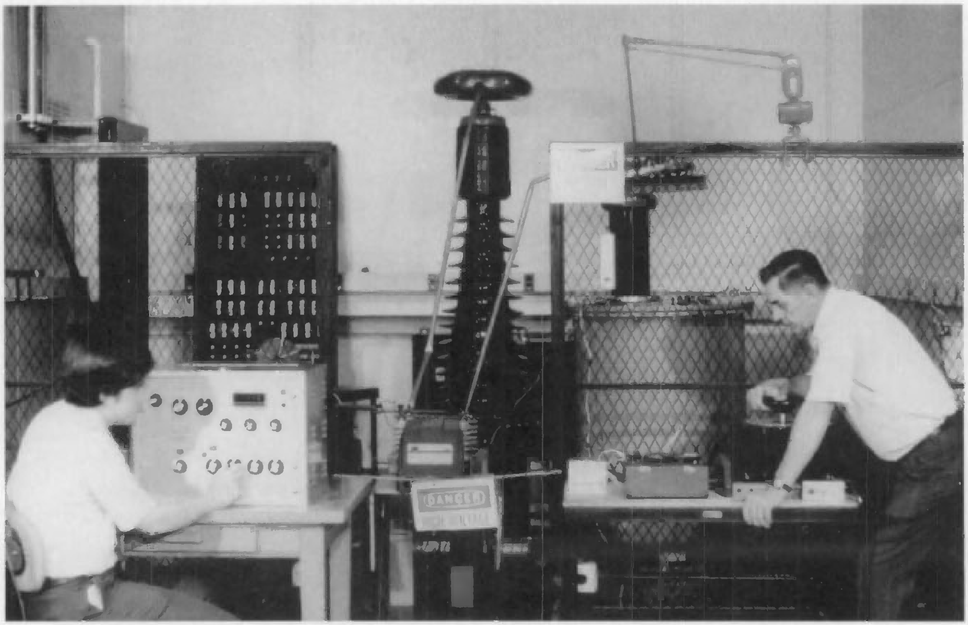
Looking for Cleaner Power from Coal

During the tenures of President Nixon and Director Roberts, the Nation searched earnestly for new sources of energy. Especially desired were new, cleaner uses for America's large domestic supply of coal.

[183] Other studies in the OHT included the spread of smoke and flame in fires; building foundations; piping materials; the thermal performance of entire buildings; design criteria for air conditioning; accelerated aging of building components; and the economics of housing. See *NBS Technical News Bulletin,* August 1972, p. 193.

[184] O. Petersons and W. E. Anderson, "A wide-range high-voltage capacitance bridge with one PPM accuracy," *IEEE Trans. Instrum. Meas.* **IM-24,** No. 4, pp. 336-344 (1975). See also "Shunt reactor power loss," *NBS Tech. News Bull.,* April 1973, p. 91.

Philip A. Cramp, a chemist with the NBS Center for Building Technology, operated a portable X-ray-fluorescence instrument to measure lead levels on the exterior wall of a house.



Chief of the NBS High Voltage Measurements Section Walter J. Mangan (standing) and Presidential Intern William E. Anderson used the self-balancing high voltage capacitance bridge to perform a power loss measurement.

John B. Wachtman and Samuel J. Schneider wrote a brief summary of U.S. needs for more efficient and cleaner power generation from coal, followed by a description of the hostile environments existing in high-temperature gas turbines, magnetohydrodynamic power generators, and coal gasifiers. The need for data and test methods was reviewed, and known material properties were summarized.[185]

Some progress was made during the period in the arcane study of magnetohydrodynamics (MHD), wherein a conducting stream of hot, ionized gas was passed through a transverse magnetic field, producing electric current in electrodes placed in the gas stream. Since it was expected that the power extracted by the MHD apparatus would be nearly free of the polluting products commonly found with coal or oil combustion, the option seemed well worth pursuing. However, the technique had its own drawbacks; high temperatures (typically above 2000 °C), a corrosive atmosphere produced by alkali-salt seed materials, and large temperature gradients.

With support from the Department of the Interior Office of Coal Research, Bureau scientists studied the resistance of known MHD materials to the corrosive MHD environment. They also investigated the properties of materials that might be used in MHD systems.

[185] J. B. Wachtman and S. J. Schneider, "Measurements and standards for high temperature materials in energy conversion and clean fuel production," *Stand. News* **1**, No. 8, 16-23 August 1973.

One form of MHD used as a fuel a type of coal, either natural or synthetic. Bureau scientists studied the composition, electrical conductivity, and viscosity of natural coal slags and the resulting fly ash, using chemical techniques, x-ray analysis, and thermal analysis. The natural variability of coal from different sources lent extra interest to the study. The composition and chemical reactions to be found in the gasified slag also were examined, along with the chemical and physical properties of known and potential seed materials that would be introduced into the system to increase gas-phase conductivity.

Technical results obtained during the period July 1972 to July 1974 were reviewed for a program initiated to generate properties data on materials for MHD. The program, sponsored jointly by NBS and the Office of Coal Research, involved a sizable group from the Bureau: Samuel J. Schneider, Webster Capps, Hans P. R. Frederikse, William R. Hosler, Dale A. Kauffman, Ernest M. Levin, Clyde L. McDaniel, Taki Negas, and Ernest R. Plante. Data were obtained in the reporting period for phase equilibria, electrical characteristics, and vaporization. Information was also obtained on the viscosity of several MHD components: coal slag materials, alkali seed materials, electrodes, and insulators.[186]

One of the projects involved measurements by Frederikse and Hosler of the electrical conductivity of coal slag—some natural and some synthetic—in the range 1200 K to 1700 K, at very low (10^{-6} of atmospheric) O_2 pressure. The authors expressed surprise that the measured conductivity was as high as 10^{-2} ohm^{-1} cm^{-1} at 1700 K, and they speculated on the cause, which they thought might be a ferrous-ferric electron transfer.[187]

Modeling the Fusion Plasma

The tantalizing concept of controlled nuclear fusion as an inexhaustible energy source coaxed large sums of money from supporting agencies and enormous amounts of effort from scientists in those days. The Bureau participated in the search in several of its laboratories.

One such effort, in its initial stage at that time, sought to provide a model of the fusion plasma to be used in developing instruments and analytical techniques for the evaluation of temperatures and electron densities. The project involved the use of a wall-stabilized electric arc burning in a hydrogen atmosphere, operated by a cosmopolitan team that included William R. Ott and Wolfgang L. Wiese of the Bureau's Optical Physics Division; Kurt Behringer, a guest worker from the Technical University in Munich, Germany; G. Gieres of the University of Dusseldorf in Germany, and Patrick Fieffe-Prevost, a visiting scientist from the National Bureau of Metrology in Paris.

[186] S. J. Schneider, W. Capps, H. P. R. Frederikse, W. R. Hosler, D. A. Kauffman, E. M. Levin, C. L. McDaniel, T. Negas, and E. R. Plante, "High temperature MHD materials," *NBSIR 74-543* 129 pp., August 1974.

[187] H. P. R. Frederikse and W. R. Hosler, "Electrical conductivity of coal slag," *Proc 13th Symp on engineering aspects of magnetohydrodynamics, Stanford U, March 26-28, 1973 paper* IV. 4. 1-IV. 4. 3.

The team built the electric arc to produce temperatures as high as 24000 K, hotter than the surface of the sun. Eight electrodes created the arc discharge, and 24 water-cooled copper discs restricted it to a volume 2 mm in diameter. Along its center, the arc temperature reached its maximum values; therefore, its properties were viewed "end-on."

The arc produced enormous amounts of radiation in the vacuum ultraviolet (vuv) region, just as a fusion plasma would. The continuum emission from the arc was employed as a radiometric standard. Its range, 165 nm to 360 nm in 1973, was expected to reach deeper into the vuv region upon further refinement.[188]

By 1975, the behavior of the arc was better understood, and its wavelength range extended down to 124 nm.[189]

Saving Energy at NBS

John D. Hoffman, Director of the Institute for Materials Research, summarized the activities of an NBS Energy Task Force that was created to develop contingency plans to keep the laboratories functioning in the event that energy conservation became mandatory.

Hoffman noted that NBS used about 115 million kWh of electrical energy and some 780 billion btu of heating fuel annually. About 85 % of the energy was used for climate control. Viable conservation measures were identified and implemented as parts of the program, including reduction in lighting, zone shut-downs of air handling, and thermostat adjustments. These steps saved about 12 % in electrical power usage and abut 18 % in heating fuel annually. Further conservation measures were considered feasible if conditions warranted.[190]

Alternative Fuels for Vehicles

Another contribution from the Bureau on behalf of energy technology was initiated by David A. Didion and James E. Hill of the Thermal Engineering Systems Section, Center for Building Technology. They adapted two NBS vehicles—a half-ton and a one-ton truck—to operate on gaseous fuels. The goal of the project was to compare engine performance with those fuels—compressed natural gas and liquefied petroleum gas (propane)—to that achieved with gasoline.

The testing group monitored emissions of hydrocarbons, carbon monoxide, and nitrogen oxides. They found that the gaseous fuels burned much cleaner (factors of three to ten) than gasoline in each category.

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[188] W. R. Ott, P. Fieffe-Prevost, and W. L. Wiese, "VUV radiometry with hydrogen arcs, I: Principle of the method and comparisons with blackbody calibrations from 1650 Å to 3600 Å," *Applied Optics* **12**, No. 7, 1618-1629 (1973).

[189] W. R. Ott, K. Behringer, and G. Gieres, "Vacuum ultraviolet radiometry with hydrogen arcs, 2: The high power arc as an absolute standard of spectral radiance from 124 nm to 360 nm," *Appl. Opt.* **14**, No. 9, 2121-2128 (1975).

[190] "Energy conservation at the NBS laboratories," *NBSIR 74-539*, 81 pp., July 1974.

NBS scientists compared the performance and exhaust emission characteristics of motor vehicles run on gasoline, compressed natural gas, and liquefied petroleum gas for the U. S. Postal Service. In this photograph, David K. Ward made engine adjustments during a test on a half-ton truck.

Whether the U.S. government, with its 300,000 to 400,000 vehicles, would switch a significant number of them to the cleaner-burning fuels was problematic. The change would involve refitting the carburetion system of each vehicle for use with the new fuel, as well as enaction of a scheme for supplying the gases in the quantities and at the locations needed for convenient use. But at least government vehicle managers now had factual information on which to base decisions.[191]

New Ideas in Physics

In this section we highlight Bureau advances in instrumentation that markedly improved the ability of scientists to make physical measurements.

[191] "Comparative performance of motor vehicles operated on gasoline, compressed natural gas, and propane," *NBS Tech. News Bull.*, August 1973, pp. 188-190.

High-Precision Spectrophotometer

A new spectrophotometer built by Klaus D. Mielenz and Kenneth L. Eckerle was expected to noticeably improve the quality of measurements in its field. The reliability of the basic unit of luminous intensity—or brightness—depended on the quality of the instruments used in its realization, so that improvements such as the one made by the two optical physicists was important progress in defining the standard.

Mielenz and Eckerle achieved new spectrophotometric accuracy by incorporating off-axis mirror optics rather than traditional lenses, and by placement of the sample in a collimated and linearly polarized beam. They also were able to compensate more effectively for detector non-linearity in the new instrument.

The new spectrophotometer employed a grating-type monochromator with circular entrance and exit apertures; it also incorporated a stabilized tungsten-ribbon lamp. A low-power laser was built into the system for alignment of the device. The detector was a photomultiplier tube with a stabilized power supply.

Early tests with the spectrophotometer indicated an instrumental uncertainty of approximately 10^{-4} transmittance units and an imprecision about half that large.[192]

A "Topografiner" Looks At Metal Surfaces

A closer look at metal surfaces became possible through the development of a new type of instrument by Bureau physicists Russell D. Young, John F. Ward, and Frederic E. Scire. Given the name "Topografiner," the prototype device permitted the topographic mapping of metal surfaces with a vertical resolution of 3 nm.[193] Clearly this was an instrument with a bright future.

Young, the team leader, came to NBS from Pennsylvania State University, where he mastered the science of field-emission microscopy under Erwin W. Müller. In a detailed 1971 article in the journal *Physics Today,* Young pointed out the value to surface science of an instrument that would allow surface measurements at the atomic level.[194] He mentioned several instruments, including one of his own, that could possibly reach atomic resolution.

The elements of the topografiner were few: a metal field-emission point, sharpened to a radius of about 10 nm; two orthogonal piezoelectric drive units arranged so as to move the point assembly in a plane parallel to a test surface; a third, finer piezoelectric drive operated by a servo system so as to maintain a fixed distance between the point and the test surface; and a mechanical stabilizing technique to restrict vibration to the lowest level then possible in their laboratory.

[192] K. D. Mielenz and K. L. Eckerle, "Design, construction, and testing of a new high accuracy spectrophotometer," *NBS Tech Note 729,* 60 pp., June 1972. See also K. D. Mielenz, "Physical parameters in high accuracy spectrophotometry," *J. Res. NBS* **76A**, No. 5, 455-467 (1972).

[193] R. Young, J. Ward, and F. Scire, "The topografiner; an instrument for measuring surface microtopography," *Rev. Sci. Instrum.* **43**, No. 7, 999-1011 (1972).

[194] R. D. Young, "Surface microtopography," *Physics Today* **24**, No. 11, 42-49 (1971).

In using the topografiner, Young, Ward, and Scire prepared three-dimensional plots of the test surface from the voltages driving the three piezoelectric crystals. The plots rendered accurately the surface of an infrared diffraction grating, thus demonstrating the capability of the instrument to record the profile of a well-characterized surface.

The unusual mechanical stability of the topografiner, which was essential to its success, was demonstrated by the three physicists in a study of electron tunneling. Disconnecting the in-plane piezoelectric drives and putting aside the servomechanism for the point, the team could use the vertical drive to move the point closer and closer to a metal surface. Recording the current-voltage characteristic of the point-surface system, they were able to demonstrate for the first time metal-vacuum-metal tunneling at separations estimated to be less than 2 nm. At larger separations, they observed a gradual transition to the region governed by the Fowler-Nordheim equation.[195]

One might have expected scientific studies with the topografiner to produce elegant experiments in surface physics at NBS for years to come but, surprisingly, that was not to be. In 1972 work on the instrument was stopped by Young's supervisors so that his ideas could advance the study of industrial surface finish in another part of the Bureau. The topografiner was perhaps the first major victim of the Bureau trend towards "relevance."

Young's work with the topografiner was continued by Gerd Binnig and Heinrich Rohrer, employees of the IBM laboratories in Zurich, Switzerland. In 1986, they shared half of the Nobel Prize in physics for their design of the scanning tunneling microscope. The other half of the prize went to Ernst Ruska, who invented the electron microscope in 1931. The seminal work by Young, Ward, and Scire was noted in the Nobel documentation.

Young received the 1974 Edward Uhler Condon award for his 1971 article in *Physics Today*. He received the Department of Commerce Silver Medal Award in 1979. In 1986, he received a Presidential Citation from Ronald Reagan. In 1992, he received the Gaede Langmuir Award from the American Vacuum Society.

Young's impact on the Bureau reached even further than his personal efforts. During Young's development of the topografiner, J. William Gadzuk, E. Ward Plummer, and E. Clayton Teague, each of whose work is noted elsewhere in this volume, joined NBS specifically to collaborate with him. Each made substantial contributions to science while working at the Bureau.

Making Free Radicals Inside Lasers

Free radicals play important roles in air-pollution studies, in research on flames, in high-temperature chemistry, and in aerospace phenomena.

George H. Atkinson, Allan H. Laufer, and Michael J. Kurylo, III, found a way to overcome problems generated by the short lifetimes of many free radicals—they simply moved the radical-producing equipment into the cavity of a dye laser.[196]

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[195] Russell Young, John Ward, and Fred Scire, "Observation of metal-vacuum-metal tunneling, field emission, and the transition region," *Phys. Rev. Lett.* **27**, No. 14, 922-924 (1971).

[196] G. H. Atkinson, A. H. Laufer, and M. J. Kurylo, "Detection of free radicals by an intracavity dye laser technique," *J. Chem. Phys.* **59**, No. 1, 350-354 (1973).

Russell D. Young received the Ph. D. degree in physics from Pennsylvania State University in 1959. He worked at NBS from 1961 to 1981. His principal research interest was the characterization of surfaces. While a group leader in the Atomic Physics Division, he led the development of the Topografiner, forerunner of the scanning tunneling microscope.

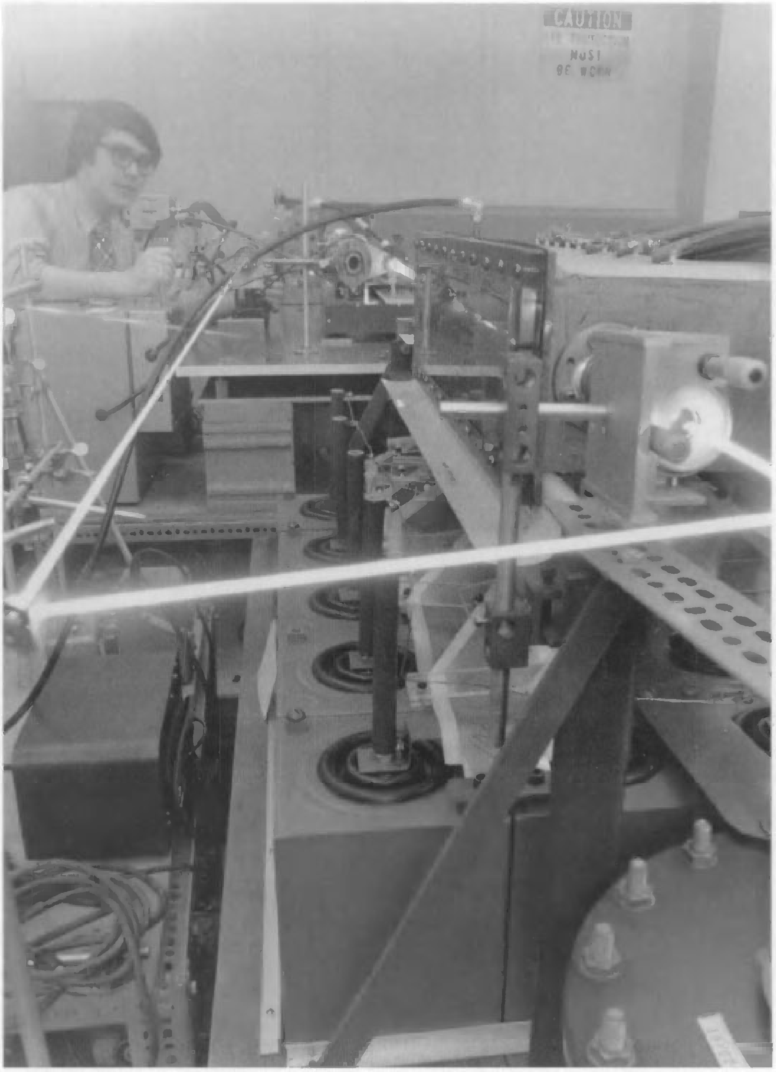
Much of the information about free radicals was obtained by observing the way in which they absorbed radiation. The NBS optical physicists found a way to incorporate the free-radical-production apparatus, a vacuum flash photolysis unit, into the cavity of a dye laser. The flash unit, consisting of a 75 cm long, fused-silica, evacuable reaction cell, utilized a 1000 J discharge to create free radicals in nitrogen gas. The dye laser, employing rhodamine 6G in ethanol, could produce about 300 mJ of output energy for analysis by a 2 meter grating spectrograph.

Early results were obtained on the species NH_2 and HCO; their spectra were more easily detected and analyzed by the new apparatus than had been the case with other techniques.

Progress in Optical Radiation Measurements

Jon C. Geist, physicist in the Optical Radiation Section of the Heat Division, initiated a new series of publications on optical radiation measurements with a 60-page treatise on the Bureau's intention to create a scale of total irradiance, using electrically calibrated, absolute detectors. His discussion included a theoretical analysis of known error sources in that type of realization, based upon detector development that occurred during the period 1968-71.[197]

[197] J. Geist, "Optical radiation measurements: Fundamental principles of absolute radiometry and the philosophy of this NBS program," *NBS Technical Note 594-1*, 59 pp, June 1972.



George H. Atkinson used a dye laser to detect free radicals, a technique that he developed at the National Bureau of Standards with Allan H. Laufer and Michael J. Kurylo.

The series was published over a several-year period as supplements to *NBS Technical Note 594*.

The second note in the series was written by Edward F. Zalewski, A. Robert Schaefer, Kshiti Mohan, and Donald A. McSparron. It described some of the basic instrumentation developed for use in photometry, including photodetector amplifiers, lamp-power circuitry, and mechanical components. Also presented were results of experiments on stability and directional-intensity tests of two types of lamps.[198]

McSparron and Velma I. Burns reviewed then-current procedures, equipment, and techniques used in photometry calibrations, including luminous intensity, luminous flux, and color temperature. Details of the uncertainty calculations associated with the program were discussed, as well.[199]

The next contribution to the series was written by Bruce Steiner, who described the National Measurement System for Radiometry and Photometry, emphasizing the role played by NBS in improving the system. Steiner noted the impact of optical-radiation measurements on the electro-optics industry—an industry that itself affected U.S. public health and safety, energy, meteorology, agriculture, and environmental activities. He also pointed out the many areas where improved capabilities for measurement were needed.[200] Steiner continued his discussion in a second note that emphasized the roles played in the measurement system by the Council for Optical Radiation Measurements and other professional groups.[201]

Details of the stability and temperature characteristics of certain photodetectors were described in a 1973 contribution to the optical-radiation-measurements series. Mohan, Schaefer, and Zalewski compared selenium-barrier-layer photocells and silicon PIN and PN type photodiodes operated in the photovoltaic or non-biased mode. The physicists studied detector-output stability over one-day periods and they investigated fatigue and hysteresis effects, as well as the temperature dependence of the detector output, all with an eye to using the devices for goniometric flux measurements or in other radiometric or photometric applications.[202]

William B. Fussell used the series to describe a new theory of the photometric integrating sphere.[203] The theory involved certain approximations to the geometry of the sphere, its baffle and lamp, and the absorptive and reflective characteristics of the sphere interior. Fussell then offered a method for evaluation of the measurement errors associated with use of the sphere. He also tabulated the diffraction losses for a range

[198] E. F. Zalewski, A. R. Schaefer, K. Mohan, and D. A. McSparron, "Optical radiation measurements: Photometric instrumentation and research (1970 to 1971)," *NBS Technical Note 594-2,* 44 pp., September 1972.

[199] V. I. Burns and D. A. McSparron, "Optical radiation measurements: Photometric calibration procedures," *NBS Technical Note 594-3,* 35 pp., November 1972.

[200] B. Steiner, "Optical radiation measurements: The impact of radiometry and photometry and the role of NBS," *NBS Technical Note 594-4,* 56 pp., March 1973.

[201] B. Steiner, "Optical radiation measurements: The present state of radiometry and photometry," *NBS Technical Note 594-6,* 56 pp., March 1974.

[202] K. Mohan, A. R. Schaefer, and E. F. Zalewski, "Optical radiation measurements: Stability and temperature characteristics of some silicon and selenium photodetectors," *NBS Technical Note 594-5,* 16 pp., June 1973.

[203] W. B. Fussell, "Optical radiation measurements: Approximate theory of the photometric integrating sphere," *NBS Technical Note 594-7,* 39 pp., March 1974.

of experimental geometries, for wavelengths from 0.2 μm to 100 μm. He included in his discussion general formulas for the losses—derived from the Kirchhoff scalar paraxial diffraction theory—as well as estimates of the uncertainties of the tabular values.[204]

Ninth in the optical radiation measurements series was a contribution prepared by William H. Venable, Jr. and Jack J. Hsia. In it, the authors developed a mathematical description of spectrophotometric measurements.[205]

Crystalline Response to Shock Waves

Donald H. Tsai, trained at the Massachusetts Institute of Technology in aeronautical engineering, had a natural interest in shock waves. He indulged the interest by initiating a long-term study of the response of crystal lattices to shock waves. By 1974, Rosemary MacDonald—a theoretical physicist and colleague of Tsai's in the Heat Division's Equation of State Section—was collaborating with him on the problem.

The two scientists developed a molecular dynamics mathematical model to account for the propagation of shock waves in three-dimensional crystals. Their 1974 theoretical "experiments" were performed with a computer on perfect base-centered-cubic crystals equipped with an interatomic potential originally created for α-iron. They made the crystals as large as could be accommodated by the available computers—125 unit cells. To study thermal relaxation with their model, they followed the propagation of high-temperature heat pulses into the crystals, observing the phenomenon of second sound, which they concluded was a quite general property of excitation in the solid state.[206]

Tsai and MacDonald refined their model and their computations, using ever larger crystals and more detailed analysis as computational capability—obtained from large computers outside NBS—increased. In 1976, they were able to comment on first sound, which they found to be a high-velocity sound wave that left behind it changes in both kinetic and potential energy in the crystal. These changes did not quickly come into equilibrium. They also found that second sound was a slower thermal wave, which did reach equilibrium. In their work, they had extended the concept of second sound to high temperatures and high pressures.[207] In a summary written later for the journal *Reviews of Modern Physics*, D. D. Joseph and Luigi Preziosi commented:

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[204] W. B. Fussell, "Optical radiation measurements: Tables of diffraction losses," *NBS Technical Note 594-8*, 39 pp., June 1974.

[205] W. H. Venable, Jr., and J. J. Hsia, "Optical radiation measurements: Describing spectrophotometric measurements," *NBS Technical Note 594-9*, 49 pp., November 1974.

[206] Donald H. Tsai and Rosemary A. MacDonald, "Heat pulse propagation in a crystal: a molecular dynamical calculation," *Solid State Communic.* **14**, 1269-1273 (1974).

[207] D. H. Tsai and R. A. MacDonald, "Molecular-dynamical study of second sound in a solid excited by a strong heat pulse," *Phys. Rev.* **B14**, No. 10, 4714-4723 (1976).

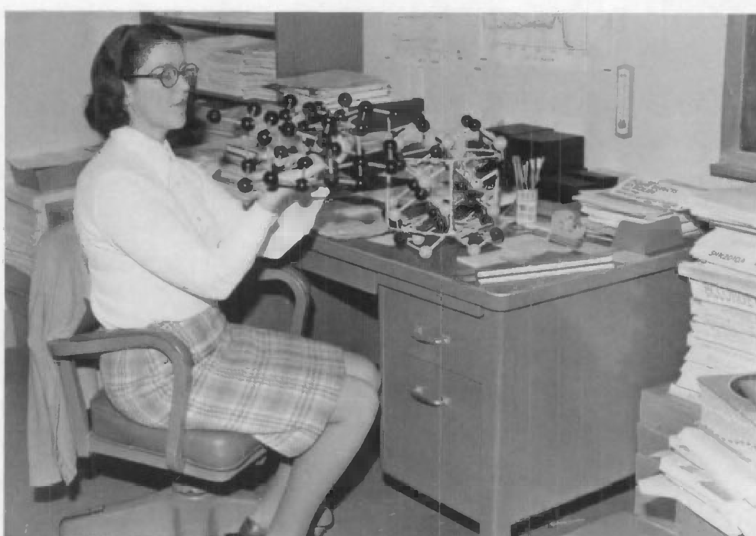
> The correspondence between the theory and calculations of this paper for high temperatures and short times and, to some degree, the experiments on second sound in helium II and dielectric crystals at very low temperatures and longer times, is astonishing.[208]

Tsai continued to work on shock dynamics even after retirement from NBS, gradually considering the effects of crystal imperfections such as vacancies, dislocations, and impurities. These, he found, led to structural relaxation under shock loading and to the generation of "hot spots" in the crystal.

Advice for Inventors

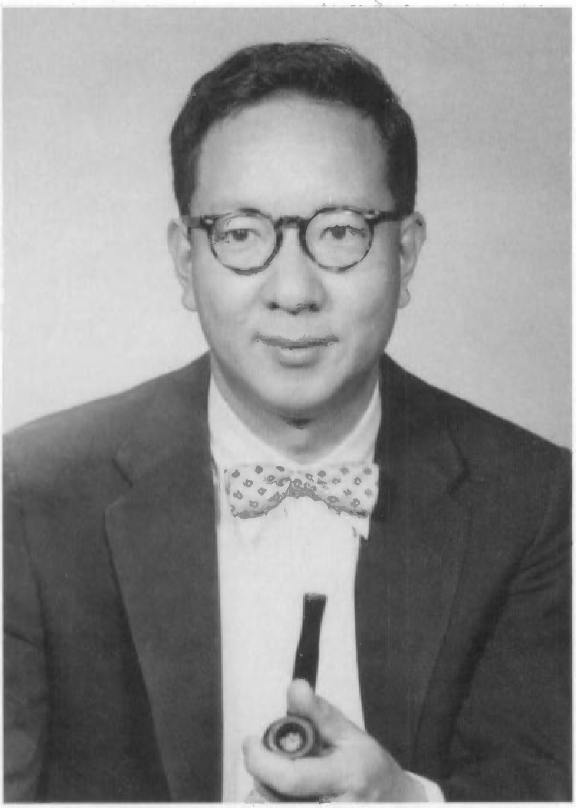
During a conference on *The Public Need and the Role of the Inventor,* held during June 11-14, 1973, at Monterey, California, Jacob Rabinow, the Bureau's dean of inventors, had sobering words for the day's image of the "wealthy" inventor:

> If that's your notion of the typical modern-day Edison, forget it. Nowadays, when an inventor is on the way to the bank, he's probably crying all the way because he has to borrow money to finance his latest quixotic gamble.



NBS physical theorist Rosemary A. MacDonald held a model intended to show the distortions in a crystal that resulted from an incoming shock wave.

[208] D. D. Joseph and Luigi Preziosi, "Heat waves," *Revs. Mod. Phys.* **61**, No. 1, 41-73 (1989).



Donald H. Tsai joined the Engines and Lubrication Section of the NBS Heat and Power Division in 1952. He was one of the first members of the Equation of State Section of the Heat Division when it was formed in 1961; his principal research interest there was the dynamical response of crystals to shock waves.

Rabinow was a reliable source.[209] He had a lifetime of invention behind him, including such important devices as a magnetic automobile clutch, an automatic letter-sorting system for the U.S. Post Office, and an optical character reader.

The conference mentioned above was co-sponsored by NBS, the Department of Commerce, and the National Inventors Council (NIC). Rabinow and F. Essers edited the proceedings, which were published as an *NBS Special Publication.*[210] There were 18 featured speakers, including Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology; Richard W. Roberts, the new Director of NBS; Charles Stark Draper, Chairman of the NIC; Robert D. Tollison, senior economist on the President's Council of Economic Advisors; and Daniel V. De Simone, executive director of the Federal Council for Science and Technology, formerly head of the Bureau's Metric Study program.

[209] The outspoken Rabinow offered advice to inventors in several ways—often by individual counseling, as sometime director of the NBS Office of Innovation and Invention, and through his writing. Author of many articles on invention and the problems encountered by inventors, Rabinow late in his career wrote a book, *Inventing For Fun and Profit,* (San Francisco, California: San Francisco Press, 1989).

[210] "The public need and the role of the inventor," *NBS Special Publication 388*, F. Essers and J. Rabinow, editors, 215 pp., May 1974.

The "invention conference" was held to make more clear the climate in which America's inventors labored and to seek changes that might encourage invention for the benefit of the Nation. Topics included the patent system, technology trends, possible incentives for inventors, and the relationships among inventors, corporations, and academia.

A few months earlier, Director Roberts attended a National Inventor's Day celebration staged by the American Patent Law Association.[211] Rabinow, chief research engineer in the Institute for Applied Technology, received recognition:

> For his many significant contributions as an inventor, for his unique ability to stimulate others to create and innovate, and for his continuing dedication to the highest principles of the patent system.

By that time, Rabinow already held 200 American patents and about 70 foreign ones. Equipped with an M. S. degree in electrical engineering from the City College of New York in 1938, he tackled the invention process fearlessly. As a result of his efforts, he received numerous awards, including the Naval Ordnance Department Award (1945), a National Defense Research Committee certificate of commendation (1945), the Presidential Certificate of Merit (1948), the Department of Commerce Gold Medal (1949), a War Department certificate of appreciation (1949), Fellow of the IEEE (1956), the Franklin Institute Edward Longstreth Medal (1959), the 50th Anniversary medal of the City College of New York School of Engineering (1969), the Jefferson Medal of the New Jersey Patent Law Association (1973), the Harry Diamond Memorial Award (1977), Scientist of the Year award, Industrial Research and Development magazine (1980), Doctor of Humane Letters, Towson State University (1983), and the Lemelson Award of the Massachusetts Institute of Technology (1998).

During the year of his death, 1999, Rabinow was honored by the Cosmos Club of Washington, DC, as Man of the Year.

Progress in Computer Science

Networking With Minicomputers and Microcomputers

As the trend began of supplementing the use of mainframe computers with smaller computers, each dedicated to specific jobs, the question of networking—interconnecting—the so-called "mini" or "micro" computers became an area of interest for the Bureau's computer experts.

Thomas N. Pyke, Jr., provided a discussion of the applications in which the smaller computers might be suitable, and the configurations which the interconnections could take. Pyke pointed out that, if the trend continued, as seemed likely, new standards written especially for those systems would become necessary.[212]

[211] "Rabinow Honored by Patent Law Association," *NBS Standard,* March 1973, p. 1.

[212] T. N. Pyke, Jr., "Networked minis and micros—configurations, applications, and standards," *Proc. Symp. on Mini Micro Computers, U.S. Naval Academy, Annapolis Maryland, April 15, 1975* pp. 44-46.

Jacob Rabinow, an electrical engineer, was a successful inventor. He worked at NBS from 1934 to 1953 and from 1972 until his retirement in 1989. He provided technical leadership to the Bureau in ordnance development and in the evaluation of inventions. He received many honors for the quality of his work.

First model of a letter-coding station for an automatic mail sorting machine built by Rabinow Engineering Company under contract to NBS. Letters, one at a time, were presented to the operator who read the addresses, abbreviated their important parts, and typed the abbreviations onto the backs of the envelopes by means of a special printer. The printing code was in a binary form, and appeared in the form of "dot" or "no dot" on the envelope. The operator was John McDonald.

More About Networking

Dennis W. Fife, chief of the Software Analysis Section of the Institute for Computer Science and Technology, addressed the issue of "networking" computers for typical user organizations. He noted that networking allowed sharing of resources and rapid communication among the network users. He identified five stages of networking, ranging from the simplest—merely interconnecting the machines—to more advanced tèchniques involving several participating institutions.

Fife also provided guidance for management in the form of an evolutionary framework against which institutional goals could be measured.[213]

Ira W. Cotton addressed the same topic, but from the point of view of a study summarizing the practices of managers employing different types of computer networks. Several examples of successful networks were reviewed: the Advanced Research Projects Agency network; the MERIT network; the Triangle Universities Computation Center network; the Oregon State Regional network; and TYMNET, a commercial version.[214]

Data Encryption

Sending proprietary information via telephone lines or electromagnetic broadcast signals became a risky business as methods matured for intercepting such communications. One alternative to abandoning the techniques altogether involved data encryption. Dennis K. Branstad, commenting on the problem, noted that various levels of encryption were available. By employing user identification, access authorization, and access control machinery, the user could reduce considerably the likelihood of compromised data.[215]

FORTRAN Test Programs

One of the first computer programming languages was called FORTRAN. A draft American National Standard document, X.3.9-1966, described the language in standard form. In order to provide a mechanism by which a FORTRAN user could determine whether a particular compiler would accept the forms and interpretations specified in the standard, Frances E. Holberton and Elizabeth G. Parker prepared a test program which they described in a series of informative publications.

The series was named the *NBS FORTRAN Test Programs.* They were made available in *NBS Special Publication 399.* Three volumes were published in October 1974. Volume 1, Documentation for versions 1 and 3; Volume 2, Listings for version 1; and Volume 3, Listings for version 3.

Nuclear Physics

An indication of the range of the Bureau's program in nuclear physics, including theory, instrument development, measurements, and standards, is given in this section.

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[213] D. W. Fife, "Network management for expanded resource sharing," Chapter 7 in *Facts and Figures* pp. 55-61 (Princeton, NJ: The Interuniversity Communications Council, 1974).

[214] I. W. Cotton, "Network management survey," *Proc. Hawaii Int. Conf. on Systems Sciences, Univ. of Hawaii, Honolulu, Hawaii Jan. 8-10, 1974.*

[215] D. K. Branstad, "Encryption protection in computer data communications," *Proc Fourth Data Communications Symp., Quebec City, Canada, October 7-9, 1975* pp. 8-1 to 8-7.

Defining Ionizing Radiation

As a first step in portraying the use of radiation for the sterilization of medical and biological materials for the International Atomic Energy Agency, William L. McLaughlin and N. W. Holm composed a brief discussion of the physical characteristics of ionizing radiation.[216]

In a few pages they reviewed the physics and chemistry involved in the interactions of ionizing radiation with matter. They noted the quantities used in monitoring energy deposition by radiation as well. The objective of the project was to show how radiation could be used to inactivate fungi, bacteria, and viruses without significant damage to the host material.

Half-Lives of Radioactive Species

A determination of the half-life for decay of ^{252}Cf was recounted by Valentine Spiegel, Jr. He obtained the value (2.638 ± 0.007) years as the half-life for the rare isotope. The accuracy of the value derived from careful measurements over nearly five years, coupled with corrections for the contribution of activity from radium in the sample and for competing neutron-production from ^{250}Cf atoms.[217]

Radiation Exposure Standards

New exposure-rate standards were set for ^{60}Co and ^{137}Cs by the Bureau as a result of measurements made using a new spherical type of ionization chamber. The measurement corrections involved with the new chambers were evaluated more accurately than had been the case with the cylindrical chambers used previously, according to Thomas P. Loftus and James T. Weaver, Jr.[218]

Measurements were obtained using six replicas of the spherical chamber; agreement among the results was described as "excellent." The experiments led to reductions in the standards for safe exposure to radiation from the two nuclides. As of July 1974, the exposure standard for ^{60}Co was reduced by 0.7 % and that for ^{137}Cs was reduced by 0.8 %.

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[216] W. L. McLaughlin and N. W. Holm, "Physical characteristics of ionizing radiation," chapter 1 in *Manual on Radiation Sterilization of Medical and Biological Materials* Technical Report No. 149, International Atomic Energy Agency, Vienna, Austria, 1973.

[217] V. Spiegel, "The effective half-life of californium-252," *Nucl. Sci. Eng. Tech. Note* **53**, No. 3, 326 (1974).

[218] T. P. Loftus and J. T. Weaver, "Standardization of ^{60}Co and ^{137}Cs gamma-ray beams in terms of exposure," *J. Res. NBS* **78A**, No. 4, pp. 465-476 (1974).

Sum Rules for Photon-Proton Scattering

A new sum rule relating to elastic photon scattering was derived by Leonard C. Maximon and James S. O'Connell. The rule described forward Compton scattering between photons and protons. The two scientists obtained the new rule by deriving the relations between integrals over forward elastic-photon scattering amplitudes, forward elastic cross-sections, and total cross-sections, using the applicable dispersion relations.[219]

Radionuclide Metrology

A new international summer school on radionuclide metrology provided several Bureau scientists with opportunities to lecture on their specialties in 1972. The school was held in Yugoslavia during late August 1972. Among the talks were the following:[220]

The work of J. M. Robin Hutchinson, Wilfrid B. Mann, and Patricia A. Mullen on sum coincidence counting at NBS was described. The use of two thallium-activated sodium iodide crystal detectors resulted in order-of-magnitude improvement in the accuracy of the sum-peak technique of coincidence counting. The method became comparable in accuracy to the conventional beta-gamma and gamma-gamma coincidence counting methods. The new technique was applied to ^{94}Nb, ^{88}Y, ^{26}Al, and ^{207}Bi.

A review of low-level radioactivity measurements was offered by Hutchinson, Mann, and R. W. Perkins. They described the sensitivities of a variety of detectors used for alpha, beta, and gamma rays. They also presented examples of low-level measurements—a standard reference material incorporating bovine liver, and radioactive contaminants in industrial samples of aluminum, copper and steel.

The development by Samuel B. Garfinkel, Mann, and John L. Pararas of automatic sample changers for the NBS 4π beta-gamma coincidence counter and the gamma-ray intercomparator was discussed. The new devices permitted the automatic measurement of as many as 30 sources for up to ten counting periods each. Good control of source-detector distances was an additional advantage of the instruments.

Wilfrid Mann presented a review of NBS work on radioactive calorimetry, with particular emphasis on the standardization of ^{63}Ni. Mann discussed the results of intercomparisons involving two Canadian laboratories, the National Research Council and Atomic Energy of Canada Limited.

[219] L. C. Maximon and J. S. O'Connell, "Sum rules for forward elastic photon scattering," *Phys. Lett.* **48B**, No. 5, 399-402 (1974).

[220] *Proc. First Intl. Summer School on Radionuclide Metrology, Herceg Novi, Yugoslavia, August 21-September 1, 1972,* printed in *Nucl. Instrum. Methods* **112**, Nos. 1 and 2 (1973).

A survey was presented by Lucy M. Cavallo, Bert M. Coursey, Garfinkel, Hutchinson, and Mann on the growing need for higher skills and improved facilities in radioactive-assay work. They noted that the value of commercial use of radio-isotopes had already reached $80 million annually. In the face of such a demand, the Bureau had to develop new strategies to satisfy it; these were discussed, with special emphasis on the use of radiopharmaceuticals and environmental measurements.

Welcome to CAMAC

CAMAC, a modular instrumentation system used to transmit digital data between instruments, between instruments and computers and between instruments and computer peripherals, was described in a series of publications by Louis Costrell. The CAMAC system was developed by a committee of European laboratories. Its use was endorsed by the Nuclear Instrument Module Committee of the U.S. Atomic Energy Commission.[221]

Costrell, at that time chief of the Radiation Physics Instrumentation Section, was a much-decorated veteran of nearly 30 years of service to NBS. In 1967, he was awarded a Department of Commerce Gold Medal for his work in nuclear instrumentation. In recognition of his contributions to many developments, including the CAMAC project, he was presented with the Harry Diamond Award in March, 1975. The citation recognized a career "that exemplified the highest type of scientific effort in Government service."

Electronic Technology

Semiconductor Measurement Technology

NBS Special Publication 400 provided an extensive reference literature in electronic technology of that time. Fourteen publications were offered in 1974 and 1975 in the series.

- Volumes 1, 4, 8, 12, and 17 were edited by W. Murray Bullis. They described NBS methods of measurement for semiconductor materials, process control, and device development during the third quarter of 1973 (Volume 1, issued March 1974, 68 pp.), the first quarter of 1974 (Volume 2, issued November 1974, 101 pp.), the second quarter of 1974 (Volume 8, issued February 1975, 70 pp.), the third quarter of 1974 (Volume 12, issued May 1975, 59 pp.), and the fourth quarter of 1974 (Volume 17, issued November 1975, 79 pp.). Accomplishments included measurement of current and capacitance on metal-oxide-semiconductor (MOS) capacitors, evaluation of transistor die attachments, analysis of interlaboratory comparisons of electron scattering in transistors, and a variety of other activities.

[221] L. Costrell, "CAMAC instrumentation system—introduction and general description," *IEEE Trans. Nucl. Sci.* **NS-20**, No. 2, 3-8 (1973).

- Volume 2, edited by George G. Harman, was 109 pages long. It was issued in January 1974. Entitled *Microelectronic ultrasonic bonding,* it contained excerpts of work in that area over the previous 4 years, arranged so as to provide a useful and coherent reference to NBS efforts in ultrasonic bonding. Specific topics included measurement equipment; setup and reliability of bonding machinery; bonding examples; and bond properties.

- Volumes 3 and 9, edited by Harry A. Schafft, summarized presentations at two workshops co-sponsored by NBS and the Advanced Research Projects Agency. The first workshop was entitled *Measurement problems in integrated circuit processing and assembly;* the second, *Hermicity testing for integrated circuits.*

- Volume 5, edited by George J. Rogers, David E. Sawyer, and R. L. Jesch, was entitled *Measurement of transistor scattering parameters.* It contained 53 pages and was issued in January 1975. In it, the authors discussed the results of an interlaboratory comparison of electron-scattering parameters for three types of transistors. The results indicated a need for more careful control of measurement methods if the participating laboratory personnel wished to obtain data with minimum variation from measurement to measurement.

- Volume 6, edited by Martin G. Buehler, contained an overview of microelectronic test patterns. It contained 24 pages and was issued in August 1974. The test patterns considered were designed to evaluate fabrication processes, allowing the operator to determine, for example, whether a given process was under control and produced reliable microcircuits.

- Volume 10 contained a report of a symposium on spreading-resistance measurements, held at NBS Gaithersburg during June 1974. The editor was James R. Ehrstein. The text of 293 pages included both contributed papers and the transcripts of discussions.

- Volume 11, edited by Richard L. Mattis and Martin G. Buehler, described a computer program for calculating dopant density profiles from capacitance-voltage data. The program was written in the BASIC language.

- Volume 13, edited by Alvin H. Sher, was entitled *Improved infrared response technique for detecting defects and impurities in germanium and silicon p-i-n diodes.* Sher enumerated the many advantages of the method and warned of its few limitations.

- Volume 20, edited by John M. Jerke, was titled *Optical and dimensional-measurement problems with photomasking in microelectronics.* Jerke described the purpose of photomasks and the processes by which they were utilized in integrated circuit production, as well as the problems in their use.

The series furnished a comprehensive, up-to-date set of references on semiconductor measurement methods.

Electronic Devices in the U.S.S.R.

Charles P. Marsden collected data on active devices, ranging from receivers to microwave devices, semiconductors, phototubes, and thermistors, in the Soviet Union. The information was obtained from a variety of published sources.[222]

Resistivity Of Silicon

Round-robin measurements suggested by the Resistivity Task Force of the American Society for Testing and Materials Committee F-1 indicated that an improved standard procedure for measurement of circular silicon slices with four in-line probes could be accomplished with a resulting imprecision near 2 %.

The experimental procedures followed in the study were detailed by W. Murray Bullis. Non-uniformity of wafer resistivity appeared to limit the precision of most measurements, but corrections for temperature, wafer thickness and diameter, and improper probe position also were noted as important variables.[223]

In another study, Bullis and W. Robert Thurber reviewed the status of resistivity and carrier-lifetime studies in gold-doped silicon, particularly dwelling on remaining inconsistencies in experimental results on three topics: an apparent discrepancy between total and electrically active gold; a discrepancy—observed in specimens with large gold concentrations—between calculated and measured resistivity in both n-type and p-type materials; and the unexpected diversity in data on capture cross sections.[224]

Thermal Impedance of Power Transistors

Discrepancies appearing in measurements of the thermal impedance of power transistors using two different methods were discussed by David L. Blackburn and Frank F. Oettinger. It seemed that the pulsed-heating-curve method gave values different from those obtained with the cooling-curve technique. The two scientists discovered that the discrepancies arose because the power density distributions changed as the devices were heated, leading to different results depending upon the direction of heat flow. They provided an analytical method for obtaining reproducible values.[225]

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[222] C. P. Marsden, "Tabulation of published data on electron devices of the U.S.S.R. through December 1973," *NBS Technical Note 835,* 130 pp., November 1974.

[223] W. M. Bullis, "Standard measurements of the resistivity of silicon by the four-probe method," *NBSIR 74-496,* 75 pp., August 1974.

[224] W. R. Thurber and W. M. Bullis, "Resistivity and carrier lifetime in gold-doped silicon," *Air Force Cambridge Research Laboratories Report AFCRL-72-0076,* 37 pp., January 1972.

[225] D. L. Blackburn and F. F. Oettinger, "Transient thermal response measurements of power transistors," *Proc. IEEE Power electronics Specialists Conf, Bell Telephone Laboratories, Murray Hill, NJ, June 10-12, 1974,* pp. 140-148.

CHAPTER FOUR

A DURABLE DIRECTOR (July 1975–March 1989)

The *NBS Standard,* official employee bulletin of the Bureau, printed on July 16, 1975, the letter of resignation written to President Gerald Ford at the end of June by Director Roberts.[1] On the same page was printed Ford's letter of acceptance and a message from Roberts to the staff explaining his reason for leaving NBS.

The front page of that issue was given to an account of the designation of Ernest Ambler to the post of Acting Director of NBS:

> On June 30, 1975, Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology, designated Ernest Ambler Acting Director of the National Bureau of Standards. Ambler fills the vacancy left by Richard W. Roberts, who has joined the Energy Research and Development Administration as Assistant Administrator for Nuclear Energy.

The account continued with the news that Robert S. Walleigh, former NBS Associate Director Emeritus, would serve as Acting Deputy Director. After Walleigh, the succession in case of Ambler's absence was given as John D. Hoffman, Director of the Institute for Materials Research; Ruth M. Davis, Director of the Institute for Computer Science and Technology; F. Karl Willenbrock, Director of the Institute for Applied Technology; and Arthur O. McCoubrey, Director, Institute for Basic Standards.

Ambler was reluctant to accept the directorship of the Bureau, but he proved to be one of its most durable directors. Nothing shows this durability more than the surprising fact that Ambler served as the leader of NBS under four U.S. presidents: he was named Acting Director in 1975 by Gerald Ford; he was nominated and installed as director in 1978 by Jimmy Carter; he served through the two terms of Ronald Reagan's presidency; and his retirement notice was received in 1989 by George Bush. For nearly 14 years, Ambler provided the continuity of leadership that had been lacking at NBS under his two predecessors.

In view of his background as a renowned physicist, Ambler might well have resisted the trend towards applied technical work that had begun for NBS during the tenure of Lewis Branscomb. But in fact Ambler embraced the trend even as it threatened the agency's traditional roles in physical and chemical standards and fundamental scientific research. Clearly, he endorsed the notion that change was as important for the future of the Bureau as it was for the future of American industry.

In the record of Ambler's lengthy tenure, we note the growth in NBS programs intended to improve the lot of American industry. By the end of his tour as director, substantial modification of the Bureau's charter was not at all surprising.

[1] *NBS Standard,* Vol. 20, No. 15, July 16, 1975, p. 2.

A Presidency in Transition

If the departure of Richard Roberts was barely noticed by the Executive Branch of the United States Government, it was because the President and his staff had a lot on their minds.

Along with the Presidency, Gerald Ford had inherited "stagflation" in August of 1974. Stagflation was the name given to an economically unhealthy combination of rising inflation and falling consumer demand for goods. Other problems—a difficult, ignoble disengagement from Vietnam; a substantial and growing foreign-trade deficit; a falling stock market; and increasing unemployment—added to his woes. He was "the man who pardoned Nixon," the nominal head of a political party that could not gain control of Congress and might lose the White House as well in the 1976 elections.

At the time he received the resignation of NBS Director Richard Roberts, Ford had just completed a difficult quarter-year. April 1975 had seen the evacuation of all Americans and many South Vietnamese from Saigon while the capital was under fire from North Vietnamese troops. On May 12, the *S. S. Mayaguez,* an American merchant ship, had been seized off the Coast of Cambodia and its crew kidnapped by Cambodian forces. In an angry but controversial reaction, Ford had ordered the Marines to retake the ship and free the crew. The recovery was completed successfully, but with the sobering loss of nearly 40 U.S. fighting men. At home, Ford had to face a request from New York City for $1 billion to stave off bankruptcy; Ford refused, demanding that the city first reform its spendthrift policies before expecting U.S. help.

As if all these problems were not enough, Ford found that he had to veto many Congressional spending bills that were pushing the national debt to unprecedented heights. Only a sturdy self-confidence and the discipline born of years of dealing with today's problems—never mind yesterday's or tomorrow's—enabled the embattled President to maintain a steady grip on the office left him by the first Presidential resignation in U.S. history.

Ford had promised his wife after the 1972 elections that the 1974 Congressional campaign would be his last. Still young enough to practice law privately and earn the "big money" which had not been his lot as a Congressman,[2] yet a veteran politician with no real hope of realizing his personal ambition to become Speaker of the House, Ford had been prepared to leave government service. Completing Agnew's term as Vice President, he had opined, "would be a nice cap to my career."[3] But now he was President of the United States, a whole new ballgame for the former Michigan linebacker.

Within 10 days after his inauguration as the 38th President of the United States, Ford had nominated Nelson A. Rockefeller to be Vice President. This action was dictated by the 25th Amendment, just as his own nomination by Nixon had been ordained by the necessity to maintain the Constitutional line of succession to the

[2] In 1968, Congressional pay was $30,000 per year—an amount easily spent by a family of six.

[3] James Cannon, *Time and Chance: Gerald Ford's Appointment With History* (New York: Harper Collins, Publishers, 1994) p. 206.

Presidency. Rockefeller, the second non-elected Vice President of the United States, was subjected to the same detailed scrutiny of his patriotism and integrity that Ford himself had endured. Found satisfactorily blameless, Rockefeller was easily confirmed by both houses of Congress and sworn to the office on December 19, 1974.

Somewhat to his own surprise, Ford found that he liked being President. He shared with Harry Truman more than the fact that each had suddenly been thrust into the Oval Office; like Truman, he faced each day's multitude of crises with vigor. He was used to hard work, he knew the Congress well from long years as a powerful insider, and he was on good terms with nearly all of his colleagues. Although Ford was a friendly man by nature, he could say "No" to friend and foe alike without second thoughts where he saw the country's welfare at stake; he vetoed 66 bills—mostly spending bills that he regarded as profligate—during his truncated tenure (fewer than 900 days) as President.[4]

Despite his early statements that he would not seek further public office after serving out the balance of Agnew's term as Vice President, Ford decided to run for the presidency in 1976.

A possible tipoff to the date of Ford's decision can be found in his appointment of Rogers C. B. Morton as Secretary of Commerce. Ford left in place Nixon's Secretary of Commerce, Frederick B. Dent, until February, 1975; then Ford asked Dent to serve as chief U.S. trade negotiator. After Dent's departure from Commerce, Ford nominated Morton on March 27, 1975. It was supposed that Morton would be heavily involved in any race for the presidency, and indeed that proved to be the case.

Much of the day-to-day interaction between the Director of the Bureau and the Department of Commerce during this period involved the office of Assistant Secretary of Commerce for Science and Technology. Betsy Ancker-Johnson, appointed by President Nixon, held that post from 1973 until the end of Ford's term as President in 1977.

Late in 1975, the post of Under Secretary of Commerce, with supervision over technical matters, was created in the department. Its first incumbent was James A. Baker, III, a Texas lawyer. He became the immediate supervisor of Betsy Ancker-Johnson. After only a few months as Under Secretary, however, he moved on to work on Ford's re-election campaign.

In January 1976, President Ford asked Rogers Morton to leave his post as Secretary of Commerce to take a position as White House counselor on economic and domestic policy, as well as "incidental duties of liaison with the President's re-election committee and the Republican National Committee."[5] To replace Morton and Baker, Ford nominated Elliot Richardson and Edward O. Vetter. Richardson was an unusually capable leader who had previously served as Secretary of Health, Education, and Welfare; Secretary of Defense; Attorney General; and, most recently, Ambassador to Britain. Vetter, a graduate of the Massachusetts Institute of Technology, was a veteran

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[4] Ibid., p. 404. "I know of no friend I lost in Congress because I told them they were wrong," he said. "The truth is that usually after a veto, Congress came back with more realistic legislation that I could sign." Only 12 of his vetoes were overturned.

[5] James M. Naughton, *New York Times*, January 14, 1976, p. 16.

of a decade of work in oil engineering and two decades as an executive in the Texas Instruments Company. Ancker-Johnson, as noted, remained at her post until replaced by President Carter.

Fallout from the Watergate disaster continued throughout the presidency of Gerald Ford. Controversy over his quick pardon of Richard Nixon, with its consequent frustration of the investigative and prosecutorial work of the Select Senate Committee, dogged the President. To counter the unfavorable publicity, Ford ordered investigations of the Central Intelligence Agency and the Federal Bureau of Investigation in order to restore their public images, which had been tarnished by his predecessor. He cut taxes by some $16 billion and reduced Federal spending in a determined effort to decrease the unusually high (more than 9 %) level of unemployment that he confronted in 1975. But nothing Ford was able to do could erase the image of government gone bad.

Although Ford entrusted Vice President Rockefeller with important domestic responsibilities, including leadership of his Domestic Council and of the Presidential Commission on the CIA, Rockefeller decided in November, 1975, that he would leave the political scene at the end of Ford's term in 1977.

Ford's bid for re-election in 1976 was vigorously contested by Ronald Reagan, former Governor of California. Ford won the Republican nomination, but he and his running mate, Senator Robert Dole of Kansas, were narrowly defeated by the slate of Jimmy Carter, former Governor of Georgia, and Walter Mondale, former Senator from Minnesota. After Ford relinquished the presidency to Carter, he made good on his promise to his wife; they retired to private life in California, to be seen thereafter only rarely in the news.

JAMES EARL CARTER, JR.

"Jimmy" Carter came to Washington as an outsider. In the 1976 elections, the Republican leadership expected serious trouble because the American public was deeply offended by the spectacle of Watergate and the distressing view it offered of a lawless and mendacious President.

Carter identified himself as independent of the machinations of Washington and he promised honesty in government. He delivered on both claims, but only at the expense of an often-discouraging unfamiliarity with the reins of Federal management that helped make him a one-term President.

Carter graduated from the United States Naval Academy in 1946. He finished in the top 10 % of his class, and was rewarded with a choice assignment in Admiral Rickover's nuclear navy. He was appointed an officer on the submarine Sea Wolf and served in that capacity for several years. Eventually he decided not to make a career of service in the Navy. He resigned his commission in 1953 to return to farming in Georgia.

After a successful decade as a farmer, Carter took an interest in politics. He sought and won two terms as a Georgia State Senator in 1962 and 1964, and he won the Georgia governorship in 1970. As Governor, Carter undertook a vigorous reformation of the Georgia government: he issued a public call for an end to racial discrimination in the state; and he reorganized the government, calling for zero-based budgeting and so-called "sunshine" legislation. Zero-base budgeting, in Carter's view, was the answer to outmoded government bodies and commissions. Under this principle, each agency would be required to begin each year with a defense of its entire budget, in effect annually justifying its own existence. The National Bureau of Standards management was to find this process burdensome when Carter attained the office of President. "Sunshine" laws were similarly simple in concept; with few exceptions—such as discussions of personnel—all agency meetings were to be announced in advance and open to the public. Logical enough to the public that it lives on throughout government today, the idea was radical and unwelcome to many a bureaucrat.

Having succeeded in his forays into state government, Carter set his sights on the national scene. He recognized the antipathy of the American people to the wretched record of the Nixon administration, so he undertook a campaign for President in 1976 that promised, as an "outsider," to return honesty and good government to Washington. A quiet, sincere, yet forceful speaker, Carter entered some 30 state primary elections and accumulated sufficient electoral backing to win the Democratic nomination on the first ballot. He defeated such Democratic competitors—all "insiders"—as Senator Henry M. Jackson, former Director of the Peace Corps Sargent Shriver, and Representative Morris Udall. With Senator Walter F. Mondale helping cement support in the mid-West and East, and buttressed by his own popularity in the South, Carter narrowly defeated Ford in the 1976 presidential race.

Carter immediately emphasized his desire to break with the past by walking, rather than riding in a limousine as was customary, from the U.S. Capitol to the White House during his inaugural proceedings. He also quickly sold the presidential yacht.

Juanita M. Kreps, a Professor of Economics, was selected by Carter as his Secretary of Commerce. She was the first woman to occupy that post. She was confirmed by the Senate on January 20, 1977, and sworn in on January 23rd. Sidney Harman was named Under Secretary, and Jordan J. Baruch—like Vetter, an MIT graduate—was appointed Assistant Secretary for Science and Technology.

As president, Jimmy Carter continued to practice the economy and openness in government that had served him well in Georgia. He promised to place a ceiling on the number of Federal workers, and he proposed a comprehensive reform of the Civil Service system. He met the crisis in energy with a plan he called "the moral equivalent of war." He established a Department of Energy in October of 1977 and obtained a large increase in funding for energy research. In 1979, he separated the Department of Health, Education, and Welfare into two—a Department of Education and a Department of Health and Human Services.

In mid-1979, Carter replaced Under Secretary Harman with Luther H. Hodges, Jr., a professor of business at Duke University. A year later, Kreps left her post, to be succeeded by Philip M. Klutznick. At the same time, the title of Baruch's position was changed to reflect a new emphasis on industrial competitiveness: Baruch became the Assistant Secretary for Productivity, Technology, and Innovation.

Carter's efforts as President often seemed tinged with naiveté. His attempts to improve respect for human rights—especially in the Soviet Union—were seen by the Soviets as interference by a nation that still had plenty of human rights violations of its own. His efforts to heal the economic ravages brought by inflation and imported oil left the country in 1980 with worse inflation—from 4.8 % in 1976 to 12 % in 1980—and high unemployment—at 7.7 %, only a slight improvement over the Ford presidency.

When Iranian "students" entered the U.S. embassy in Teheran and took some 63 U.S. citizens as hostages in November 1979, Carter's effectiveness as a national leader was questioned. For more than a year the United States was unable, by force or by diplomacy, to liberate the hostages.

During a speech carried on national television, Carter graded his administration harshly; C+ to B on foreign policy, C on domestic policy, A on energy, C on the economy, and B on leadership.[6] Little wonder that the ticket of Carter and Mondale received only 42 % of the popular vote in the 1980 presidential race against Ronald Reagan and George Bush.[7]

RONALD WILSON REAGAN

Without doubt, Ronald Reagan was a man of his times. Sportscaster, movie star, television-show host, video-advertising icon, Governor of California—Reagan embodied the full gamut of the era of communications. He also covered the political spectrum, changing his philosophy from liberal Democrat to conservative Republican as he shed his acting career for a new life in government.

Reagan was as self-assured as Jimmy Carter had been self-questioning. Trained from his youth in mass communication, he projected confidence even when discussing issues that were much in doubt. Joining with George H. W. Bush to campaign for a conservative America, Reagan easily defeated incumbent President Jimmy Carter and his running mate, Vice President Walter F. Mondale.

Nearly 70 years of age when he took office, Reagan's stamina and outlook were the envy of men decades younger. He rejoiced in the opportunities that the presidency offered—glittering parties, banquets with heads of state, speeches on the greatness of America and the evils of Communism, thoughtful discussions with captains of industry, horseback-riding vacations at Camp David and at his beloved ranch in California, political debates with Democrats. No one, seemingly, could find a fault in Reagan—especially Democrats, who always seemed tongue-tied by comparison with the "Great Communicator."

In fact, from all points of view save one—that of fiscal responsibility—Reagan's two terms as President were successful.

[6] James M. Burns, *The Crosswinds of Freedom*, (New York: Vintage Books, 1990) p. 530.

[7] Hedrick Smith, *The Power Game: How Washington Works* (New York: Random House, 1988), p. 674.

Reagan's presidency suffered a rocky start. Only 3 months into his presidency, Reagan was shot by John W. Hinckley, Jr., not a political assassin but a dangerous psychopath. Reagan proved to have been very lucky to have survived the attack (Hinckley's bullet lodged very near his heart, and he lost nearly half his blood before emergency physicians could stop the flow). His doctors reported amazement at Reagan's strong physical condition and the speed of his recovery from the attack.

Reagan's second year as president, 1982, was marred by a recession which slowed his progress in implementing his campaign promise of a strongly conservative, strongly nationalistic government.

Reagan's presidential policy was made to order for counteracting an economic slump. Confront the "evil empire" at every opportunity, increase defense spending, decrease non-defense spending, reduce taxes—these were the simple tenets by which the Reagan administration prospered. America's defense industry quickly led the way to economic well-being.

On December 11, 1980, Reagan named Malcolm Baldrige, Jr., as his choice for Secretary of Commerce. Six other Department heads were revealed on that day. Baldrige, 58, was a successful businessman, most recently as Chairman of the Board of Scoville Manufacturing Company of Waterbury, Connecticut. Long active in Connecticut and national politics, Baldrige had the distinction among Reagan's nominees of being the only member of the Rodeo Cowboys Association.

Reagan abandoned the posts of Under Secretary for Science and Assistant Secretary for Science and Technology. NBS Director Ernest Ambler thus found himself more closely involved with the office of the Secretary of Commerce, a situation that pleased Ambler.[8]

In the 1984 presidential campaign, the Reagan-Bush team defeated the challenge presented by Walter Mondale and his running mate, Geraldine Ferraro, with only modest effort. Questions regarding his advanced age, as always, were dismissed by Reagan with a jaunty smile and a ready quip.[9]

Secretary of Commerce Baldrige remained at his post until his untimely death on July 25, 1987, while riding in a rodeo. He was succeeded in August 1987 by Acting Secretary Clarence J. Brown. In turn, Brown was replaced in October 1987 by C. William Verity, Jr., retired chairman of Armco Steel Company.

Reagan demonstrated his self-confidence and his devotion to conservative government early in his presidency. During his first year in office, 1981, he ordered a freeze on the hiring of Federal employees and fired the nation's air-traffic controllers when they struck for better working conditions.

With Vice President Bush as point man and a Republican majority in the Senate, Reagan pushed a tax-reduction program to reduce the maximum Federal income tax rate from 70 % to 50 % and the maximum capital-gains rate from 28 % to 20 %.

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[8] Ernest Ambler, Oral History, September 22, 1988.

[9] During a televised presidential debate, Reagan pre-empted the age question. He stated that he knew that age was considered a factor in the election but, although he was well aware that Mr. Mondale was "young and inexperienced" by comparison to himself, he promised that he would not dwell on that fact during the campaign.

These tax cuts were to be funded at the expense of social programs, but not defense expenditures; among the first cuts was the synthetic fuels program. America would increasingly be strong in the face of Communism, and Americans at the top of the economic heap would be happy.

A Strategic Defense Initiative—called "Star Wars" by skeptical critics—was begun in 1983. The SDI program was intended to prevent attack on the United States mainland by mid- or long-range missiles. It was to feature defensive weapons that incorporated the latest in technology, including high-powered lasers. All government agencies, including the National Bureau of Standards, worked feverishly to configure technical projects as helping to create, to detect, or to shoot down space-based weapons.

In the same year, the United States invaded the tiny island of Grenada in response to a request by the Organization of Eastern Caribbean States. It took only a few days for U.S. Marines and Rangers, aided by troops from six Caribbean nations, to eliminate the Marxist threat from that source.[10]

President Reagan generally showed little interest in the mechanics of Executive Branch agencies, many of which he regarded as unnecessary. An exception occurred in 1987 when he paid a surprise visit to a federal meeting on high-temperature superconductors and proposed a new project (see A Presidential Initiative later in this chapter).

The U.S. economy, buoyed by what was essentially a war effort against Communism, boomed as it always has during a war. The principle involved in war-economy boom times is simple, though slightly flawed: American industry is heavily employed in the manufacture of goods that are bought by the American government and disposed of in the process of conducting foreign policy; wages are reliable, employment stays low, and the standard of living is good.

The flaws in Reagan's policies, skyrocketing national debt and trade deficits—the budget deficit alone reached $180 billion during 1984—were unfortunate but virtually unavoidable companions to the defense-based economic boom.

Let this important truth be stated clearly, however: not only did Reagan's militaristic foreign policy send the U.S. government deeply into debt, but it also sent the "evil empire" into bankruptcy. The Soviet Union, out-spent and eventually kopeck-less, was forced to call off the Cold War. The Union itself was dissolved by vote of its people and, on November 9, 1989, the Berlin Wall began to be dismantled. This was Reagan's greatest legacy, in the view of many historians.

By 1988, Reagan was 77 years old but still vigorous. Had he not been limited to two terms by law, he might have run again. However, under the circumstances he happily supported his Vice President's campaign to succeed him. George Bush chose Senator Danforth Quayle of Indiana as his running mate. The two easily defeated Massachusetts Governor Michael Dukakis and Texas Senator Lloyd Bentsen, although the Democratic Party retained control of both houses of Congress.

[10] Mark S. Hoffman, editor, *The World Almanac and Book of Facts,* (New York: Pharos Books, 1988) p. 454.

Ernest Ambler, Temporarily an Acting Director

Ernest Ambler became the first naturalized citizen to head NBS. Born in Bradford, Yorkshire, England in 1923, he was educated at Oxford University, receiving the D. Phil. degree in 1953. Immediately upon graduation, he was recruited by NBS to assist in physics research at extremely low temperatures, using the method of adiabatic demagnetization of paramagnetic samples. Ambler became a U.S. citizen in 1958.

The ability of NBS to undertake experiments at temperatures below one kelvin eventually won world-wide recognition for Ambler and for his Bureau colleagues; their work proved vital to the success of an experiment demonstrating the failure of the physical principle of conservation of parity in weak interactions. The "parity experiment," suggested by physicists Tsung-dao Lee and Chen Ning Yang of Columbia University, won for them the 1957 Nobel Prize in physics.

Ralph P. Hudson shared with Ambler the responsibility for the cryogenic aspects of the parity experiment. Hudson, instrumental in bringing Ambler to NBS,[11] was Chief of the Cryogenic Physics Section of the Heat and Power Division when the parity experiment got under way. Raymond W. Hayward and Dale D. Hoppes, both members of the Radioactivity Section of the Atomic and Radiation Physics Division, were responsible for the radiation physics portion of the experiment.

In 1961, Director Allen Astin appointed Hudson Chief of the Heat Division and Ambler Chief of the division's Cryogenic Physics Section. In 1965, Ambler became Chief of the Inorganic Materials Division. In 1968, Astin made Ambler Director of the Institute for Basic Standards. When Lawrence Kushner left NBS in May 1973 for the post of Commissioner of the Consumer Products Safety Commission, Director Richard Roberts appointed Ambler Deputy Director of NBS.

By nature, Ambler was inclined to speak plainly, not always a recipe for successful management. He later recalled his years as a working scientist as among his happiest and most exciting times, but noted that, as his management responsibilities continued to grow, he came to enjoy as well his administrative role.[12]

Even as he was named Acting Director of NBS following the abrupt resignation of Richard Roberts in June 1975, Ambler questioned his own suitability to deal successfully with the Congress. Asked if he would be interested in the position of Director on a permanent basis, his surprising answer was, "No." His logic was simply put in a later memoir:[13]

> The prospects facing any new Director were not very attractive, especially with the justification of Federal budgets getting ever more difficult. Besides, one had the feeling that the scientific and technical community thought that if a real

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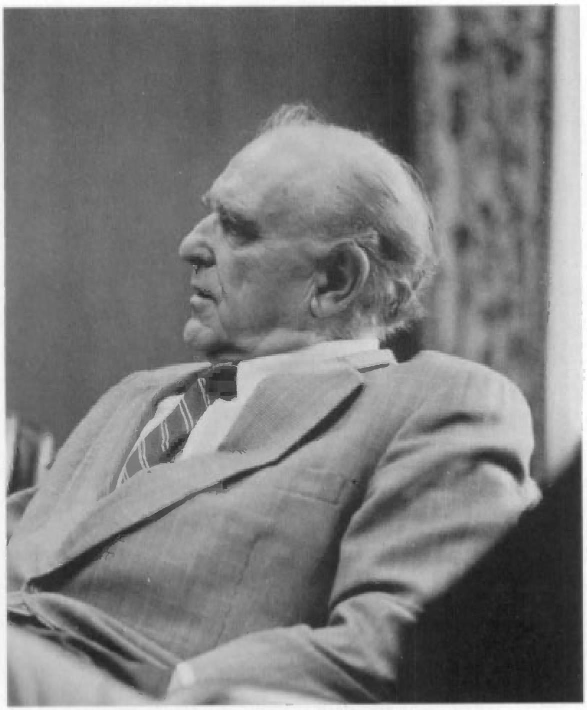
[11] Ernest Ambler, Oral History, July 7, 1988.

[12] Ernest Ambler, Oral History, July 27, 1988. See also Ernest Ambler, "Historical Perspective: 1973-1989," in *NBS/NIST, a Historical Perspective: A Symposium in Celebration of NIST's Ninetieth Anniversary, March 4, 1991*, Karma A. Beal, Editor, *NIST Special Publication 825*, April 1992, p. 38.

[13] Ibid., p. 32.



Ernest Ambler was the eighth director of NBS. Only Samuel Stratton and Allen Astin exceeded his tenure as head of the agency.

> "mover and shaker" were appointed, the forces arrayed against agencies like the Bureau could be overcome. Well, I was not convinced that the "great man" theory was correct, and in any case I knew I was not such a person.

Despite his personal ambivalence towards the job, Ambler agreed in 1975 to serve as the acting Director of NBS, a post he held from July 1975 to February 1978.

A New Administrative Structure for NBS

During an ad hoc meeting with NBS managers on September 12, 1977, Ernest Ambler proposed the first major reorganization of NBS since 1964, and only the second top-to-bottom change in agency history. In creating the "institute" structure in 1964, Allen Astin recognized the difficulty of managing many division chiefs—their number having grown substantially by the creation of various "applied" units. Ambler stated that his principal motivation was to focus the engineering units of the Bureau on the traditional engineering disciplines and to help them meet the demands of modern technology.[14] But Ambler's proposal was not limited to the NBS engineering units—virtually every employee was affected by the change.

[14] Ambler, *SP 825*, p. 34.

On its face, it seems remarkable that an Acting Director—one who was uncertain whether he wanted the job on a permanent basis—would propose to remake his agency. Such a sweeping reorganization might be expected from a director with considerable experience in the position. It is instructive to probe a bit to seek an explanation for Ambler's move.

A Director-In-Waiting

An important first step in understanding Ambler's 1977 proposal for reorganization is to notice a substantial change in his own status during 1976.

When Elliot Richardson became Secretary of Commerce on February 2, 1976, he took an immediate interest in the leadership of NBS. Ernest Ambler later recalled a visit from Richardson at the Bureau on March 1, 1976, only a month after Richardson had been confirmed as Secretary.

As mentioned earlier, Ambler had hesitated to seek permanent status as Director because of the increasing budget difficulties facing NBS, feeling that only a "hero" could bring home sufficient funding to properly support the Bureau. He stated his concerns to Richardson. Richardson urged Ambler to reconsider, pointing out that integrity and a high level of understanding of NBS were of paramount importance to success as head of a technical agency.

Ambler found Richardson's argument convincing, and he agreed to accept permanent status as director.[15] President Ford submitted the nomination of Ambler for director of the Bureau in June of 1976.

Once the nomination process had begun, Ernest Ambler no longer was a temporary leader of NBS with only temporary thoughts about its management. By 1977, Ambler was an appointee, awaiting formal proceedings that most likely would make him permanent director of the Bureau.

As it happened, nearly two years—until February 3, 1978— passed before Ambler's appointment was completed. The delay implied no lack of confidence by the President or the Congress in Ambler's ability to perform as director, but only a coincidental hiatus occasioned by the national election of 1976.

Upon receiving Ford's nomination of Ambler, the leadership of the responsible Senate committee initially scheduled hearings for July, 1976. The unavoidable activity accompanying an election year, however, pushed the hearings into the background.

The election of Jimmy Carter, very much an outsider in Washington, resulted in yet further delay as the new president struggled to grasp the reins of government. On November 10, 1977, Carter announced his intention to nominate Ambler to the post of NBS director. Ambler's nomination hearing took place at last on December 14, 1977. As expected, confirmation came smoothly on February 1, 1978. President Carter gave Ernest Ambler his "Commission of Office" on February 3, 1978; NBS had its eighth director.[16]

[15] Ambler, *NIST Special Publication 825*, p. 32.

[16] "Senate confirms Ambler as NBS Director," *NBS Standard* **23**, No. 3, February 8, 1978, p. 1.

A Push For Change

The second step in understanding Ambler's reorganization of NBS in 1977-78 involves an appreciation of his determination to perform his duties as he saw them.

As director of the Institute of Basic Standards a decade earlier, Ambler had made substantial organizational changes in order to modernize the scientific bases for certain of the divisions.[17] This had been his first experience with the interpersonal problems that accompany management decisions everywhere. In 1977, perceiving a need to revise the Bureau's response to current problems in technology—particularly those in engineering—Ambler did not hesitate to act.

Reorganizing to Deliver Technology

In an article in the NBS Standard of September 21, 1977, Ambler stated:

> I have been thinking about reorganization for some time, because of difficulties I have experienced working with the present organization. Also, I have been studying the proposal made by Dr. Baruch in July that the Bureau undertake programs to foster the delivery of technology to the industrial, intergovernmental and international sectors. What I shall propose will allow for the strengthening of the scientific and technical competences at NBS as well as responding more quickly and effectively to the expectations of those who use our services.

In Ambler's proposal, the four NBS institutes would be eliminated, to be replaced by "more streamlined" units. Ambler reassured the anxious staff that, although nearly all employees would be affected by the coming changes, every effort would be made to avoid loss of jobs.

A steering committee and five task forces were created by Ambler to accomplish the transition. Leading the task forces were:

- National Engineering Laboratory: John W. Lyons.
- National Measurement Laboratory: John D. Hoffman.
- Technology Programs: Howard E. Sorrows.
- Associate Directorate for Administration / Associate Directorate for Information Programs: Richard P. Bartlett, Jr.
- Financial Management, Budget, and Programs: Raymond G. Kammer.

The target date for completion of the reorganization was set as mid-October 1977. Ambler urged all employees to submit ideas and comments on the reorganization directly to the task forces.[18]

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[17] Ernest Ambler, Oral History, September 22, 1988.

[18] *NBS Standard*, Vol. 22, No. 19, Sept 21, 1977, p. 1.

Over the following 9 months, some 20 bulletins were issued to the Bureau staff describing progress toward the new organization.[19]

As approved by Assistant Secretary of Commerce Baruch in November 1977, major elements of the new organization were:[20]

- National Engineering Laboratory.
- National Measurement Laboratory.
- Institute for Computer Sciences and Technology.
- NBS/Boulder Laboratories.
- Two National Centers for Cooperative Technology.
- Administrative and Information Systems.

In separating the portions of NBS that primarily supplied engineering work from those primarily devoted to measurement, Ambler's task groups generally left standards and calibration activities untouched in their respective divisions. As a result, standards and calibration efforts were divided nearly equally between NEL and NML.

Creating a National Engineering Laboratory

Assembling a strong engineering activity at NBS was one of Ambler's principal objectives for the 1978 reorganization. Several components that could become useful parts of the National Engineering Laboratory, to be headed by John W. Lyons, already existed within the Bureau; others, in Ambler's opinion, had to be coaxed into being. Certain programs within the former Institute for Applied Technology had been quite successful, but were not suitable for the new structure simply because their functions had been taken over by private firms. Others, not based on traditional engineering disciplines, did not fit Ambler's view of NBS.

One of the most successful of all the IAT programs was the Fire Research program (see A Hectic Decade for Fire Science later in this chapter). As directed in the *Federal Fire Prevention and Control Act of 1974,*[21] the Bureau had created a Center for Fire Research, placing in it all NBS resources devoted to fire research and fire safety. John Lyons had been brought to the Bureau to head the new Center. When he was selected in 1978 to head the National Engineering Laboratory, Frederick B. Clarke was named Acting Director of CFR. The center included but two divisions, Fire Science, headed by Robert L. Levine, and Fire Safety Engineering, headed by Irwin A. Benjamin.

[19] NBS Admin. Bull. 77-46, September 23, 1977; 77-49, October 6, 1977; 77-55, October 12, 1977; 77-62, November 2, 1977; 77-64, November 7, 1977; 77-66, November 22, 1977; 77-68, November 29, 1977; 77-69, December 6, 1977; 77-72, December 15, 1977; 77-73, December 16, 1977; 78-2, January 16, 1978; 78-3, January 24, 1978; 78-5, February 6, 1978; 78-7, February 13, 1978; 78-10, March 9, 1978; 78-13, March 22, 1978; 78-14, March 28, 1978; 78-15, April 6, 1978; 78-20, May 1978; and 78-21, May 18, 1978.

[20] NBS Admin. Bull. 78-21, May 18, 1978.

[21] Public Law PL93-498, 88 Stat. 1535-1549, enacted October 29, 1974.

A Center for Electronics and Electrical Engineering, to be headed by Judson C. French, was readily formed from existing divisions and sections:

- A new Electron Devices Division, placed under the management of W. Murray Bullis, was created by renaming the former Electronic Technology Division.
- A new Electrosystems Division was formed by reassigning part of the staff of the former Electricity Division. Oskars Peterson was chosen to lead the new division.
- A new Electromagnetic Fields Division, located in Boulder under the direction of Harold S. Boyne, was created by reassigning part of the staff of the former Electromagnetics Division.
- A new Electromagnetic Technology Division, a Boulder unit under Robert A. Kamper, was formed from the remaining personnel of the former Electromagnetics Division.

A Center for Mechanical Engineering and Process Technology (CMEPT) was created from personnel from several former IBS divisions and placed under the leadership of John A. Simpson. The new units were the Mechanical Processes Division, under Russell D. Young; the Fluid Engineering Division, under George E. Mattingly; the Thermal Processes Division, under Kenneth G. Kreider; the Acoustical Engineering Division, under David S. Pallett; and the Boulder-based Thermophysical Properties Division, under Richard H. Kropschot.

Realizing later the value of separate centers for mechanical engineering and chemical engineering, Ambler in 1981 divided CMEPT into a Center for Manufacturing Engineering and a Center for Chemical Engineering.

The IAT Center for Building Technology, headed by Richard N. Wright, was essentially transferred *in toto* to the new NEL, although the new center structure was modified to include these four divisions: a Structure and Materials Division, under Edward O. Pfrang; a Building Thermal and Service Systems Division, under Preston E. McNall; an Environmental Design Research Division, under Francis T. Ventre; and a Building Economics and Regulatory Technology Division, under James G. Gross.

The IAT Center for Consumer Product Technology, headed by Stanley I. Warshaw, was transferred into the new NEL with the divisions of Consumer Sciences, under Harold P. Van Cott; Product Performance Engineering, under Andrew J. Fowell; and Product Safety Technology, under Walter G. Leight.

The IBS Applied Mathematics Division became NEL's Center for Applied Mathematics, Burton H. Colvin, Director, with divisions for Mathematical Analysis, under Frederick C. Johnson; Operations Research, under Alan J. Goldman; Statistical Engineering, under Harry H. Ku; and Scientific Computing, temporarily under Colvin.

Creating a National Measurement Laboratory

Formation of a National Measurement Laboratory, to be directed by John D. Hoffman, was considerably easier. It was to contain all of the portions of the former Institute for Basic Standards and the Institute for Materials Research that had not been commandeered to form the NEL, providing the heart of the Bureau's traditional measurement standards, physics, and chemistry activities.

A Center for Absolute Physical Quantities, to be directed by Karl G. Kessler, included divisions for Electrical Measurements and Standards, under Barry N. Taylor; Temperature Measurements and Standards, under James F. Schooley; Length and Mass Measurements and Standards, under Ralph P. Hudson; and Boulder's Time and Frequency, under James A. Barnes, and Quantum Physics (JILA), under Gordon H. Dunn.

A Center for Radiation Research, under James E. Leiss, incorporated the following divisions: Atomic and Plasma Radiation, under Wolfgang L. Wiese; Nuclear Radiation, under Randall S. Caswell; Radiation Physics, under Christopher E. Kuyatt; Radiometric Physics, under Jack L. Tech; and Radiation Source and Instrumentation, under Samuel Penner.

A Center for Thermodynamics and Molecular Science, headed by Milton D. Scheer, included five divisions. These were Surface Science, under Cedric J. Powell; Chemical Kinetics, under Wing Tsang; Chemical Thermodynamics, under David Garvin; Thermophysics, under Harold J. Raveche; and Molecular Spectroscopy, under Merrill M. Hessel. During 1981, CTMS was re-named the Center for Chemical Physics.

A Center for Analytical Chemistry, Philip D. LaFleur, Director, incorporated divisions for Inorganic Analytical Research, under I. Lynus Barnes; Organic Analytical Research, under Harry S. Hertz; and Gas and Particulate Science, under John K. Taylor.

A Center for Materials Science was formed, to be directed by John B. Wachtman, Jr. Its component divisions were Chemical Stability and Corrosion, under Thomas D. Coyle; Fracture and Deformation, under Sheldon M. Wiederhorn; Polymer Science and Standards, under Ronald K. Eby; Metal Science and Standards, under Arthur W. Ruff; Ceramics, Glass, and Solid State, under Hans P. R. Frederikse; and Reactor Radiation, under Robert S. Carter.

The Institute for Computer Science and Technology, directed by M. Zane Thornton after the departure of Ruth M. Davis, was transferred into the new organization without change.

Fine Tuning the New Organization

As might be expected, the sweeping changes wrought during the 1978 reorganization received additional modification as the new units began to fulfill their intended purposes. Notable among these was the loss of Ambler's choice as his deputy director, Thomas A. Dillon. Dillon, completing his doctoral work as a chemical physicist in 1969, quickly became an itinerant manager; he joined the NBS Program Office in 1974, the Department of Energy in 1976, NBS again (as Ambler's deputy) in 1978, and the Department of Energy again in 1980. Ambler chose Raymond G. Kammer to replace Dillon as Deputy Director.

Most changes wrought by the original reorganization plan were mentioned in the descriptions given above. Later changes included the following:

- Incorporation of the Gaithersburg instrument shop into NEL as part of the Center for Manufacturing Engineering, taking advantage of progress in computer-based machine tools. Other changes in this center left it with—besides the new Fabrication Technology Division—a Mechanical Production Technology division, under Daniel Flynn; an Automated Production Technology Division, under Robert Hocken; and an Industrial Systems Division, under James Albus.
- Re-orienting and renaming of the Center for Thermodynamics and Molecular Science as the Center for Chemical Physics, Peter L. M. Heydemann, Director.
- Appointment of James H. Burrows, a mathematician who formerly supervised data processing for the U.S. Air Force, as permanent Director of the Institute for Computer Sciences and Technology.
- Incorporation of the Computer Services Division, Martin R. Shaver, Chief, into NEL as part of the Center for Applied Mathematics.
- Addition of a Building Equipment Division to the NEL Center for Building Technology.
- Addition of a Fire Performance Evaluation Division to the NEL Center for Fire Research.
- Creation of a Center for Chemical Engineering within the NEL. This new center, filling a much-needed void in the NEL roster of engineering disciplines, was headed by Jesse L. Hord. It encompassed the Fluid Mechanics, Thermal Processes, and Thermophysical Properties divisions, earlier included in the Center for Mechanical Engineering and Process Technology.

An Expanded Role for the Institute for Computer Sciences and Technology

The Center for Computer Sciences and Technology, established in NBS in 1966 in response to the "Brooks Act" (PL 89-306, 1965), was made a separate organizational entity late in 1968 and given institute status in 1973. Its purpose was to prepare standards and guidelines for the purchase and effective utilization of computers by government agencies. Ruth Davis had seen the advantage of adding to that duty a substantial dose of computer science.

Unfortunately, when the "lead agency" concept took hold in the Federal government in the early 1980s, the Office of Management and Budget suggested that ICST should be transferred bodily to the General Services Administration, the agency in charge of government procurement.

Fate intervened, however; nearly intractable problems arose in the business and industrial sectors as they tried connecting computer components obtained from different sources. Inundated by the magnitude of the interfacing problem, they turned to NBS and to ICST for help. ICST scientists and engineers were ready with assistance based upon the creation of voluntary standards, much of it through research done at the Bureau. The Institute initiated the use of testbeds such as the Network Protocol Testing Facility, materially shortening the time and effort needed by the private sector to utilize computers as versatile business tools.

No longer did Bureau management hear suggestions that ICST was not a legitimate component of NBS.

The new organization lasted a decade. Under John Lyons, the National Engineering Laboratory sought to establish for the Department of Commerce a leadership position in industrial technology. The effort fit very well into the growing mood of Congress that there should be more that the Federal Government could do to foster competitiveness in the international arena for American firms. The consumer movement characteristic of earlier days was dying; it was being replaced by an emphasis on technology.

As noted above, Ernest Ambler's appointment as permanent director of NBS took place during the time that the last details of the 1977-78 Bureau reorganization were being decided.[22]

Reorganization Brings Stress

The first major reorganization in 13 years brought peace to some NBS staff members, but upset and uncertainty to many more.

Responding to frequent calls from distraught employees, David Lesage, an employee development specialist in the Personnel Division, collaborated with psychologist Craig Wasserman of the University of Maryland to cope with employee uncertainty and stress that was connected to the re-arrangement of most operating divisions. The result was a lecture entitled "Organizational Change—Dilemma or Opportunity."[23]

The approach taken by Lesage and Wasserman was rooted in the notion that crisis embodied both danger and opportunity. Employees who enrolled in the course were reminded of the ways in which major change could be faced while minimizing destructive thoughts brought on by disturbances in their daily routine. Three major problems surfaced; loss of contact with accustomed co-workers; loss of "hard" information; and fear of re-assignment to less desirable projects.

Employees re-located into new situations—and there were many of these—were encouraged to discuss problems—both in new duties and in personal fears—with their new supervisors.

The 1977-78 reorganization was a nerve-wracking experience for many Bureau employees. Its real significance, however, was as a harbinger of change to come. With the reorganization, Ernest Ambler created a structure that he felt could more readily serve as a resource for the engines of America's technology.

[22] *NBS Standard,* Vol. 23, No. 3, February 8, 1978, p. 1.

[23] "Exploiting opportunities of change," *NBS Standard,* Vol 23, No. 5, p. 2.

Other Administrative Activities During Ambler's Directorship

More Work for the Congressional Liaison

Esther Cassidy continued in her position of Assistant to the Director for Congressional Affairs throughout Ambler's tenure as director. In 1973, she had left the laboratory for a Commerce Science Fellowship in Congress;[24] at the end of 1974, Director Richard Roberts had appointed her to the position of Assistant to the Director for Congressional Affairs. Ambler declared that appointment of such an assistant had been one of Director Roberts' most useful steps, providing NBS with a constant and informed contact for the ever-increasing communications with Congress. He noted that in one year alone—1984—some 120 Congressional staff members came to NBS for briefings.[25]

NBS/ERDA Energy Agreement

Throughout the period when Ernest Ambler was director, the nation endured shortages of energy or rising energy costs. Frequently, both maladies were in evidence. As a result, energy conservation and alternative sources of energy to augment U.S. oil and coal supplies were continuing items in the Bureau's technical menu.

In November 1975, officials of NBS and the Energy Research and Development Administration—new home to former director Richard Roberts—signed a memorandum of understanding relating to ways that the Bureau could assist ERDA with its assigned duties. The memo provided for the transfer of funds to NBS for work in the areas of energy research and technology, including such alternative sources of energy as solar power. The agreement also embodied Bureau efforts in standards, measurement methods, and data acquisition, as well as technical consultations by NBS staff members. Considerable work was accomplished under the aegis of the agreement.

NBS Celebrates Its 75th Birthday

During 1976, NBS staged a year-long celebration of its 75th year of service to the Nation with open houses at both its Gaithersburg and Boulder campuses, exhibits, symposia, workshops, and films. The party began on March 1, with a ceremonial visit to the Gaithersburg campus by Secretary of Commerce Elliot Richardson and the opening of a 4-day symposium staged by the Institute for Basic Standards. The symposium was titled *Measurements for the Safe Use of Radiation.*

March 3, 1976, the 75th anniversary of the creation of NBS, was marked by an address by Director Ambler and by the dedication of new exhibit areas in the Gaithersburg Administration building.

Lectures by distinguished scientists—Edward Teller of the University of California, Norman Ramsey of Harvard, William O. Baker of Bell Laboratories, Henry Eyring of the University of Utah, Garrett Birkhoff of Harvard, Alan Perlis of Yale,

[24] *NBS Standard,* Vol. 20, No. 16, July 30, 1975, p. 3.

[25] Ernest Ambler, *SP 825,* p. 31.

In November 1975, during a period when the Nation's energy crisis seemed to demand action, Deputy Administrator of the Energy Research and Development Administration (ERDA) Robert W. Fri (left) and NBS Director Ernest Ambler signed a memorandum of understanding that Bureau scientists would assist ERDA in various technical capacities.

Robert C. Seamans of the Energy Research and Development Administration, and Simon Ramo of TRW Corporation—were given at Gaithersburg during March and April. A similar series at the Boulder laboratories opened with Arthur Schawlow of Stanford University, who spoke on February 11.

On April 5, the Institute for Applied Technology sponsored a symposium on Fire Standards and Safety.

A 3-day symposium on Computers in a Democratic Society was presented by the Institute for Computer Science and Technology during July. Also in July, the National Conference on Weights and Measures met in celebratory session on the Gaithersburg campus.

From September 20-24, a symposium on Methods and Standards for Environmental Measurement was presented by the Institute for Materials Research.

Open houses were held on the Gaithersburg campus from May 6-8 and on the Boulder grounds from October 14-16.[26] An estimated 50,000 people—many of them schoolchildren—visited the laboratories and grounds of the Gaithersburg site over the 3-day period. Dozens of selected tour stops featured imaginative presentations that described arcane projects in simplified terms.

[26] *NBS Standard,* Vol 21, No. 4, pp. 1, 8, February 25, 1976; ibid., No. 5, pp. 1-8, March 10, 1976; ibid., No. 10, pp. 4,5,8, May 19, 1976. Further details were given in other 1976 issues of the periodical.

At a former NIKE missile base adjacent to its Gaithersburg site, NBS engineers tested solar collectors in a project sponsored by the Energy Research and Development Administration. A key part of solar heating and cooling systems, the collectors were lowered into the former missile silos when not under test.

NBS scientist Freddy A. Khoury explained research in synthetic surgical implants to school children at an NBS Open House held in 1976.

The Fiscal Year Moves to September 30th

During 1976, the fiscal year of the Federal government was delayed by a quarter-year to give the Congress more time to appropriate funds for government activity for another 12 months. The end of Fiscal Year 1976 took place on June 30, 1976; then a short, quarter-year funding cycle carried all the agencies through to September 30, 1976, whereupon Fiscal Year 1977 began.

The gambit could hardly be called a success, if judged by the need—which periodically recurred long after the change—for "continuing resolutions" to carry the government into a new fiscal year when the appropriations bills had not been passed in a timely fashion.[27]

[27] See, for example, Eric Pianin and Juliet Eilperin, "Hill Passes Temporary Spending Measure," *The Washington Post*, September 29, 1999, p. 1. In its lead paragraph, the authors explain, "The [Congress] voted yesterday for a temporary spending measure that would keep the government open for another three weeks as it tries to resolve internal differences . . ."

NBS/EPRI Agreement

The Electric Power Research Institute, a nonprofit organization funded by all sectors of America's electric utility industry, was created to advance electric-power technology by means that were sound not only from a technical viewpoint, but on environmental and energy-conservation grounds as well.

During 1976, Director Ernest Ambler of NBS signed a Memorandum of Understanding (MoU) with Chauncey Starr, President of EPRI, which involved the Bureau directly in EPRI projects. As might be expected, the NBS contribution was to be heavily slanted towards measurement technology—on equipment, power generation, power distribution, and methods of power usage.

Five areas where EPRI expected the most help from NBS, according the MoU, were the measurement of electrical and electromagnetic quantities, physical-properties data, evaluation of devices and control systems, mathematical and computer-aided design, and energy conservation methods at all stages of power generation, distribution, and use.

A Distinguished Federal Servant

On Jan 12, 1977, Ambler received the President's Award for Distinguished Federal Service in the East Room of the White House. The award was presented by Vice President Nelson A. Rockefeller. Ambler was the first NBS employee and only the second Commerce employee to receive the award. Secretary of Commerce Elliot L. Richardson and former NBS directors Roberts, Branscomb, and Astin also attended.[28] The citation read in part:

> His extraordinary accomplishments in the fields of low temperature and nuclear physics, his brilliant work which invalidated a previously accepted fundamental law of physics, and his leadership as Acting Director of the National Bureau of Standards, have been of great importance to the Nation and the world.

The President's Award was only the latest of many for Ambler. His experimental work with Ralph Hudson, Raymond Hayward, and Dale Hoppes, performed in conjunction with C. S. Wu of Columbia University, demonstrated the non-conservation of parity in weak nuclear interactions and earned him and his colleagues several major awards. Over the years, Ambler received the Department of Commerce Gold Medal, the Arthur S. Flemming Award, the John Price Wetherill Medal of the Franklin Institute, the NBS Stratton Award, a 1-year John Simon Guggenheim Memorial Foundation Fellowship, the Washington Academy of Sciences Award, and the William A. Wildhack Award.

[28] *NBS Standard*, Vol. 22, No. 2, January 26, 1977, p. 1.

Oversight Hearings

During the tenure of Lewis Branscomb as director, the Bureau was the subject of oversight hearings by the Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics. On October 25, 1977, another day of hearings began, this time by the Subcommittee on Science, Research, and Technology of the House Committee on Science and Technology. Remarkably, the House hearings were followed a few months later by Senate oversight hearings, the first anyone could remember.

As might have been expected, the testimony of Ernest Ambler dominated the hearings on October 25. His testimony was heavily buttressed, however, by statements from Jordan J. Baruch, the Commerce Department Assistant Secretary for Science and Technology; from Charles E. Peck of Owens-Corning Fiberglass Corporation, representing the NBS statutory Visiting Committee; and from William O. Baker of the Bell Telephone Laboratories, representing the views of the evaluation panels chosen by the National Academy of Sciences and the National Research Council to review the work of the NBS technical divisions.

Jordan Baruch, who opened the session, testified to his respect for NBS. "NBS," he said, "is in many ways a unique institution." Baruch enumerated the wide range of Bureau activities and its worldwide reputation for excellence and objectivity, praising the agency for providing the Nation with measurement know-how that spanned the scientific, technical, and commercial sectors. Significantly, Baruch pointed to NBS as a potentially powerful ally of the fading U.S. industrial prowess in the arena of international commerce.

Ambler, in the midst of staff discussions regarding the major reorganization of 1977-78 (discussed previously in this chapter), described the facilities of NBS, its staff, its budget,[29] its congressional mandates,[30] its major activities, and its problems. In discussing the last category, Ambler sounded a warning that all was not well with the Bureau. His message noted unfunded Congressional assignments, a staff too often called upon to solve short-term problems at the expense of long-term competence, and an effort to design a more effective management structure.

Peck, at that time Chair of the statutory Visiting Committee, continued the somber theme. Peck quoted from a recent report of the five-member committee:

> NBS is on the brink of serious trouble. The persistent retrenchment that has taken place threatens to bring NBS to a mediocrity that is unacceptable. Shocking gaps exist in NBS' ability to carry out its basic assignment, even without supplemental assignments. New assignments thrust on the Bureau

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[29] In Fiscal Year 1977, $70 million of direct appropriations, $48 million from other government agencies for consultations on their problems, and $6 million in calibrations and fees.

[30] These included the recent additions of the *Brooks Act of 1965; the Federal Non-Nuclear Research and Development Act of 1974; the Fire Prevention and Control Act of 1974; the Energy Policy and Conservation Act of 1975;* and the *Resource Conservation and Recovery Act of 1976.*

> without funding or personnel have forced NBS leadership into defensive management, whereby long-range programs are sacrificed to salvage short-term objectives.
>
> One study indicates that basic research in constant dollars may have dwindled to half the level of 10 years ago. Fifteen new laws since 1965 have given NBS assignments, yet the NBS overall budget in constant dollars has not increased.
>
> NBS has had four different directors in 10 years. The present head has been in an "acting" status for two years. "Temporary" management cannot do a strong job.

The Visiting Committee had pulled no punches in its condemnation of the poor care given NBS by the Office of Management and Budget, the Department of Commerce, and the Congress. Peck was glad for the opportunity to testify on behalf of the beleaguered scientists.

Speaking for the many divisional evaluation panels, Baker expressed his admiration for NBS support of the Nation's science and technology. He reviewed the existing organization of the Bureau and threw the weight of the panels behind the dire assessment given by the NBS Visiting Committee.

The hearings gave the House subcommittee some things to think about.

Senator Adlai E. Stevenson, III, chaired oversight hearings on NBS held by the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology, and Space during February and April of 1978. Stevenson confessed uncertainty regarding the precedent for Senate oversight:

> This is the first congressional oversight hearing for the Bureau in memory. We haven't been able to figure out when the last one was, if ever, in the Senate. We aim to remedy that neglect. Our objective is a strong NBS which continues to contribute to the scientific and technical capabilities of the United States.

The February Senate hearings were short. The Congress was in recess, so that only Stevenson was present. Nevertheless, four leading Bureau managers presented testimony—Ambler; John Hoffman, director of the Institute for Materials Research; John Lyons, recently appointed director of the Institute for Applied Technology; and Zane Thornton, acting director of the Institute for Computer Science and Technology. The topics discussed included the proposed NBS reorganization, which received final approval on March 8, 1978; a program in cooperative technology, included in the Fiscal 1979 budget; and overviews of the NBS institutes.

On April 6, 1978, the Senate oversight hearings continued. Jordan Baruch once again testified to the quality of work done at NBS, cautioning, however, that the Bureau was "stretched thin" by its variety of new assignments. Baruch was followed by W. Dale Compton of Ford Motor Company, William Baker of the Bell Laboratories, and George E. Brown, Jr., congressman from the 36th district of California. Once again, the nascent cooperative technology program came under discussion, along with the question of periodic oversight hearings. Ambler suggested that reviews on a 2-year or 3-year cycle might be appropriate.

Later, Congress decided that it should review the authorization of NBS funding on a 1- or 2-year cycle, in place of the continuing authorization used for so many years. Olin Teague, chair of the House Science and Technology Committee, suggested that periodic review would "assure that the Bureau of Standards will indeed be able to make its maximum contribution" to the Nation. In fact, hearings on the NBS authorization became an annual ritual.

On February 1, 1980, George Brown, chair of the House Subcommittee on Science, Research, and Technology, opened a 6-day hearing on the NBS FY 1981 budget authorization. The hearings were historic in that they were held at NBS, in the Red Auditorium.

Ernest Ambler, Thomas Dillon, John Hoffman, James Burrows, John Lyons, and Ray Kammer presented their views of the Bureau, either in prepared statements or in answer to the many questions posed by the committee members. Joining Rep. Brown were Reps. Don Fuqua and Alan Ertel. In questions and comments, the committee members expressed respect for NBS and support for its mission and needs.

Following the presentations and question-and-answer sessions, the Congressional delegation toured the Gaithersburg site.

Remaking the Civil Service

As part of his plan to streamline the Federal government, President Jimmy Carter proposed on March 2, 1978, that the Civil Service should be reformed. If accepted by the Congress, the changes would affect 2.1 million Federal employees.

Carter's proposal was intended to affect all aspects of government service—hiring and firing, pay, grievances, transfers, and retirement.

After some debate, the Senate Governmental Operations Committee voted on July 24, 1978, to support the major features of Carter's proposal, and the Civil Service Reform Act was signed by the president on October 13, 1978.

The principal provisions of the 116-page law established new job performance standards. It also established a new type of government employment, the Senior Executive Service, composed of nearly 11,000 high-level managers who were subject to re-assignment from agency to agency. The Civil Service Commission was abolished, to be replaced by an Office of Personnel Management, a Merit Systems Protection Board, and a Federal Labor Relations Authority.

It would take some time before the changes wrought by the new act would be fully assimilated by the nation's Federal civil servants.

Scrutiny From a Conservative Administration

President Reagan's avowed goal of reducing the reach of the Federal Government in areas that could possibly be served by private-sector efforts, coupled with the ever-growing budget deficit, forced NBS to justify many of its programs over and over again throughout the 1980s. Two government-wide surveys and continued scrutiny from the Administration's Office of Management and Budget kept the Bureau on constant alert.

The President's Private Sector Survey on Cost Control, chaired by J. Peter Grace and consequently known as the Grace Commission, undertook a monumental survey of the entire federal government during 1982 and 1983, looking for ways to economize. A total of 47 volumes eventually made up the report of the Commission—one of them devoted entirely to the Department of Commerce.

The 45-member Commerce Task Force spent, by their own count, 80 person-months studying the department. They suggested that substantial cost savings (some $45 million over 3 years) could be realized within NBS alone. The savings could result, they said, by eliminating certain activities that could be accomplished by the private sector and certain other activities that showed high cost/benefit ratios. Still other savings could be realized by generating more financial support for certain projects from the using public. Six of the NBS centers—Chemical Engineering, Manufacturing Engineering, Fire Research, Building Technology, Analytical Chemistry, and Materials Science—were cited as potential sources for the savings.

Fortunately for the Bureau, the "using public," which depended heavily upon NBS scientific and engineering expertise, became vocal in defense of the Bureau. Largely through their efforts, damage to NBS programs from the Grace Commission recommendations was minimal.

The White House Science Council Federal Laboratory Review Panel visited NBS on November 28, 1982. The panel was chaired by David Packard, Chairman of the Board of Hewlett-Packard Company; members included John Bardeen of the University of Illinois, D. Allan Bromley of Yale University, Donald S. Fredrickson of the Howard Hughes Medical Institute, Arthur K. Kerman of MIT, Edward Teller of Stanford University, and Albert D. Wheelon of Hughes Aircraft. The Bureau was one of 16 laboratories visited, surrogates for some 700 laboratories operated either for or by the Federal government.

The panel had been asked by George A. Keyworth, Science Advisor to the President, to review the operations of the laboratories with an eye to improving their use and performance. In contrast to the suffocating recommendations offered by the Grace Commission, NBS Director Ernest Ambler found in the *Packard Report*[31] valuable guidance for the future of the Bureau.[32]

The panel focused on five features regarded as crucial to the success of the laboratories. The features and brief synopses of panel recommendations follow:

- Mission—must be clearly defined and consistent with Federal goals.
- Personnel policies—should be changed to operate outside of normal civil service restrictions, in order to attract high-quality staff.
- Funding—should be multi-year, with 5 %-10 % devoted to independent research.
- Management—should include outside peer review of laboratory management and operations.
- Interaction with universities, industry, and users of laboratory outputs—access to Federal facilities, collaboration, and contracting should be encouraged.

[31] *Report of the White House Science Council Federal Laboratory Review Panel,* Office of Science and Technology Policy,Washington, DC, 20500, May 1983.

[32] Ernest Ambler, *SP 825,* pp. 33-34.

After meeting with Packard to discuss details of the report, Ambler was determined to follow its recommendations. He gave particular significance to refining the NBS mission with regard to assisting U.S. industrial prowess, to strengthening ties with outside organizations, and placing more emphasis on outside review of NBS work. Ambler noted several ways in which NBS improved its record during the following years:

- By 1986, the number of Industrial Research Associates at NBS reached 255, three times the number in 1980.
- By 1987, the number of cost-sharing projects with industry reached 244, with 174 different companies involved. Gifts and loans of equipment similarly increased.
- Other-agency funding and earned income both increased markedly during the 1980s.
- NBS was the scene of a 5-year *Personnel Management and Demonstration* project, beginning in 1988.

During the Reagan administration, the Office of Management and Budget, pursuing the cost-cutting effort that drove the Grace Commission, viewed several programs at NBS as candidates for elimination or privatization. The National Academy of Science-National Research Council postdoctoral research associate program, a primary source of scientific talent for NBS, was earmarked for elimination at one point. The NBS library became a candidate for privatization. The OMB questioned NBS expenses for travel, even to scientific meetings, and Bureau costs for printing and reproduction. Even funds spent for scientific consulting were challenged in a serious effort to reduce the cost of government.

All of these efforts to truncate the work of the Bureau required detailed justification, both from within and outside NBS. Most of the NBS responses came from the staff of the Bureau's Office of Programs, Budget, and Finance. The PBF staff spent the decade of the 1980s in continual motion to minimize the cost to NBS of a strong national defense.

Complicating Ambler's management during 1982 was the loss of Deputy Director Raymond G. Kammer. Kammer left on a temporary assignment to the Department of Commerce to assist the National Oceanic and Atmospheric Administration in its efforts to procure a new radar system. In Kammer's absence, John W. Lyons served as Deputy Director of NBS. As part of his new duties, Lyons utilized the opportunity to broaden his knowledge of Bureau programs and personnel.

Updating NBS Computers

NBS scientists, mathematicians, and engineers were heavily involved in computer development even before the first ENIAC (Electronic Numerical Integrator and Automatic Computer) was built at the University of Pennsylvania in 1947. At the request of the Bureau of the Census and the Office of Naval Research, NBS prepared computer design specifications for those agencies just after the close of World War II.

To test computer components, train operators, and provide computations for its own staff, the Bureau built the Standards Eastern Automatic Computer (SEAC) at the same time. It went into service during June, 1950. SEAC was the first general-purpose, stored-program computer in the U.S. It was used for 14 years; for a remarkable 4000 hours, it performed without a malfunction.

Keeping the Bureau abreast of the revolution in computers turned into a complicated problem while Ernest Ambler was still director of the Bureau's Institute for Basic Standards. The initial problem for NBS was difficult enough—to replace its badly outdated central computer. The large expense involved in the replacement had to be justified in terms of large need. As time went on, however, the issue of central main-frame vs minicomputers and even smaller units became an equally thorny one.

The situation was complicated by the rationale used to support the central computer—running time on the machine was charged to individual project funds. Machine time was sufficiently expensive that the computer was idle for a substantial portion of each day. Some staff members argued for reduced-cost or free use of the computer so that it would be utilized more fully.

During the late 1960s, minicomputers with relatively high capacity became available. As early as 1970, Harvey A. Alperin and Edward Prince of the Reactor Radiation Division reported the installation of a "medium-sized" computer that was used in a time-share mode to control data acquisition by a group of eight instruments at the NBS reactor and to perform computations in real time.[33] The most "computer literate" of the scientific and engineering staff foresaw the use of small, dedicated computers both for off-line calculations and direct interactive support of laboratory data-taking.[34] Some scientists argued that the purchase of several "mini-computers" might eliminate the need for a central facility. In fact, the Bureau administration was reluctant to allow the purchase of smaller machines for fear of weakening its case for a new central mainframe computer.

Faced with a virtual ban on minicomputers, scientists with more need for computer use than they had project funds to pay for machine time sought out colleagues in other organizations who could share time on minicomputers which, once purchased, could be used full-time with nearly no further expense.

As director of NBS, Ambler found the problem still alive and troublesome; there was still no new central computer. By 1975, the lack of computational facilities was damaging the Bureau's ability to attract top-ranking scientists to its laboratories.

Like his predecessors, Ambler saw a continuing need for a central NBS computing facility which could be used for scientific calculations and data reduction by the technical staff as well as for record-keeping and secretarial functions by the administration. His advisors envisioned a network linking individual laboratories to a central

[33] H. A. Alperin and E. Prince, "A time-shared computer system for diffractometer control," *J. Res. NBS* **74C**, Nos. 3, 4, 89-95 (1970).

[34] This viewpoint was supported by a "Statement of ADP Policy for NBS," *NBS Standard,* Vol XV, No. 8, August 1970, pp. 4-5.

"supercomputer." To this end, he continued attempts to justify and fund a new, high-capacity main-frame machine. However, requests to the technical staff for information on their present and foreseeable computer needs met with resistance; already saddled with heavy costs for computation on the outdated central computer, some staff members feared that their project funds would be hit with still larger bills if their true needs were known. Also, Ambler found himself in the unenviable position of discouraging acquisition of laboratory-size computers—ever smaller and ever more powerful—in order to maintain demand for a central computer.

Eventually NBS, largely through the personal efforts of Ambler and a substantial group of advisors including Eleazer Bromberg, Burton H. Colvin, Glenn R. Ingram, Stephen White, Richard T. Penn, John W. Lyons, and Guy W. Chamberlin, Jr., obtained both departmental permission and the money to buy a new central computer. It was delivered in 1985 and became operational in 1986.

By the time the new central computer was in place, the question of main-frame *vs* individual computer was moot. Hundreds of relatively inexpensive, powerful desk-top computers were in use to run experiments, record and process data on-line, and function as private secretaries as well. Similar stand-alone units quickly came into use in secretarial offices throughout NBS. Because the secretarial staff had no experience in word-processing, NBS provided assistance in several forms: a computer-assistance office was formed under the leadership of Patsy Saunders to create standard procedures for office computing; and a newsletter was created to take some of the "magic" out of the computerized office.

The availability of computers to run laboratory experiments at NBS, to acquire and process data, and to facilitate the communication of results constituted an enormous gain in the efficiency and productivity of Bureau scientists and engineers. Similar advantages accrued to administrative workers. But the development was a painful one.

New Legislation for NBS

During the tenure of Ernest Ambler, a raft of new legislation brought new duties to NBS. Among the new congressional acts were the following:

- *Energy Policy and Conservation Act* (PL 94-163), 1975. This act called upon the Federal Energy Administration to direct NBS in the development of appropriate test procedures relating to energy conservation, including recycled oil. At NBS, the mission of the Center for Consumer Product Technology was altered: the Appliance Labeling Section was re-named the Product Standards Development Section; the Consumer Behavior and Information Section was abolished; the Electronics and Instrumentation Section and the Electrical and Mechanical Engineering Section were combined into an Advanced Measurement Technology Section; and the Product Systems Section was re-named the Product Safety Engineering Section.

- *Metric Conversion Act of 1975* (PL 94-168). This act instructed NBS to help the National Conference on Weights and Measures with its project on metric education for state governments.

• *National Science and Technology Policy, Organization, and Priorities Act of 1976* (PL 94-282). This act established an Office of Science and Technology Policy for the White House. It also instructed the President to form a President's Committee on Science and Technology. The legislation reflected congressional disappointment over the loss of direct science advice during the Nixon and Ford administrations.

• *Energy Conservation and Production Act* (PL 94-385), 1976. In this act, the Federal Energy Administration was instructed to direct NBS in the development of energy-efficiency-improvement targets for major household appliances. The Department of Housing and Urban Development was called upon to promulgate performance standards for commercial and residential buildings.

• *Resource Conservation and Recovery Act of 1976* (PL 94-580). Provisions of this act instructed NBS to assist the Office of Solid Waste of the Environmental Protection Agency on a reimbursable basis.

• *Clean Air Act, Amendments of 1977* (PL 95-95) and Clean Water Act of 1977 (PL 95-217). In these acts, NBS was assigned to assist the EPA as requested.

• *Earthquake Hazards Reduction Act of 1977* (PL 95-124). NBS was called upon for analysis and testing as part of this Act.

• *Federal Mine Safety and Health Amendments Act of 1977* (PL 95-164). Among other provisions, this act placed the NBS Director on a mine-safety advisory committee.

• *Federal Fire Prevention and Control Act of 1974,* amendment (PL 96-121), 1979. This act updated the NBS Organic Act with respect to the 1974 law.

• *Trade Agreements Act of 1979* (PL 96-39). This act resulted in NBS becoming the inquiry point for the provision of the General Agreement on Tariffs and Trade that pertained to technical barriers to trade. It also led to the establishment at NBS of a National Center for Standards and Certification Information and to a technical office for non-agricultural products.

During October 1980, President Carter signed into law five more bills of interest to NBS:

• *The NBS Authorization Act for Fiscal Years 1981 and 1982* (PL 96-461) authorized the expenditure of $107. 6 million during Fiscal Year 1981 and $142.4 million during fiscal 1982. The act also contained two amendments to the NBS Organic Act; it increased the amount of appropriated funds available for refurbishing buildings, and it provided new authority for international activities. NBS was allowed to provide financial assistance to foreign scientists to work at NBS, and NBS employees working at foreign institutions were allowed to receive financial assistance, fellowships, and lectureships. It also allowed the Secretary of Commerce to support foreign scientists studying at NBS.

• *The Federal Emergency Management Act* (PL 96-472) authorized NBS to spend $425,000 for earthquake hazard work during fiscal 1981. It also authorized FEMA $1 million for use by NBS earthquake scientists and $4.3 million for use by the NBS fire research program (see A Hectic Decade for NBS Fire Science later in this chapter).

• *The National Materials and Minerals Policy, Research, and Development Act of 1980* (PL 96-479) required the Commerce Department to provide by January 1981 a case study identifying specific materials needed for national security, economic well-being, and industrial production. The act also required the department to provide by October 1981 an assessment and recommendation for programs to meet the identified needs.

• *The Used Oil Recycling Act of 1980* (PL 96-463) updated provisions of PL 94-163. NBS was instructed to continue its oil recycling program, but the act forbade identifying oil as recycled until the study was complete and the Federal Trade Commission had promulgated suitable labeling rules. The act also mandated assessment of environmental problems caused by improper disposal or reuse of recycled oil, analysis of the supply and demand for used oil, and comparison of the energy savings associated with refined used oil.

• *The Stevenson-Wydler Technology Innovation Act of 1980* (PL 96-480) authorized the Secretary of Commerce to create Centers for Industrial Technology, jointly financed by industry and government, and affiliated with universities or other non-profit corporations; and to develop and transfer new technologies through a Research and Technical Applications Office to industry, to state governments, and to local governments. Beginning in FY 1982, the department, along with other Federal departments with in-house research laboratories, was to set aside 0.5 % of its research and development budget for the support of technology transfer functions. Within NBS, an Office of Research and Technology Applications was established to carry out the Wydler-Stevenson activities.

• In 1981, amendments were added to the *Earthquake Hazards Reduction Act of 1977 and to the Federal Fire Prevention and Control Act of 1974.* These amendments mainly affected the NBS Fire Research Center.

• *The Federal Technology Transfer Act of 1986* (PL 99-502) established within NBS a Federal Laboratory Consortium for Technology Transfer.

• *The Computer Security Act of 1987* (PL 100-235) established within NBS a computer standards program to provide for government-wide computer security and training in computer security.

• By the end of 1987, there could be no doubt of the view of many in Congress that NBS was ideally suited to the task of transferring technology to American industry. As it had in the past, the Bureau provided quick and effective responses to congressional requests. It was time to build the new mission into the NBS Organic Act. This change was accomplished by the last legislation to be mentioned in this section: the *Omnibus Trade and Competitiveness Act of 1988* (PL 100-418), which renamed NBS as the National Institute of Standards and Technology and amended the agency's Organic Act. This act is the principal subject of the next chapter.

Foreign Guest Workers

NBS always welcomed visits by scientists from foreign countries. The numbers of foreign visitors and guest workers increased as the effect of the *NBS Authorization Act for Fiscal Years 1981 and 1982* (PL 96-461), which changed the ground-rules for foreign scientists, was felt throughout the Bureau. Visitors continued to come from the "usual" places—England, France, Germany, Australia, Japan, and the other industrialized nations— but increasing numbers arrived from countries with less industrial development. Korea, Mexico, China, and Brazil, among many others, sought to find the key to economic progress in the Bureau's activities in science and technology.

Under the Protocol for Cooperation between NBS and the State Bureau of Metrology of the People's Republic of China, for example, three guest workers—all women—reached NBS during the summer of 1980. The three, chemists interested in learning some of the newest measurement techniques, represented the Chinese National Institute of Metrology:

- Pan Xiurong, Chief of the Institute Chemistry Laboratory, was responsible for a project in standard reference materials. She came to study the Bureau's Standard Reference Materials program.
- He Xiheng, a thermodynamicist, participated in the work of the Chemical Thermodynamics Division project in refuse-derived fuels.
- Feng Fengdi, interested particularly in instrumental analytical chemistry, worked with Robert Watters on computerized trace analysis.

The three scientists were typical of a growing number of foreign visitors to NBS.

Reagan's RIF

In April 1981, nearly 3 years had passed since the 1978 oversight hearings had featured plain warnings by observers of NBS that the Bureau was seriously understaffed and underfunded. If President Reagan was aware of those alarms as his 2-term tenure began, he was indifferent to them. Reagan announced a plan to decrease the size of the Federal work force in non-defense agencies. For NBS, the edict amounted to a loss of about 300 of its employees (10 %) by the end of Fiscal Year 1982.

In the *NBS Standard* for April 29, 1981, Director Ambler noted that NBS was already over its personnel ceiling at the end of the Carter administration, having expected relief in the Fiscal 1981 budget but receiving none.

Ambler expected about 100 employees to leave via attrition and reprogramming during the 18-month period of the downsizing; the rest would be released through a Reduction in Force (RIF) action. A table was offered to identify the numbers of employees to be separated from the Bureau—by one means or another—during Fiscal 1981.

John Hoffman and John Lyons, heads of the two major NBS units, each proposed to use programmatic criteria in enacting the RIFs. A "Job Search Assistance Program" was initiated by the Bureau Personnel Division to assist employees affected by the RIF to find other work, either at NBS or elsewhere. The JSAP augmented the long-existing Employee Assistance Program.

The RIF was begun immediately after it was announced, to minimize the inevitable impact on employee morale. So-called "bumping rights," allowing employees who received RIF notices to displace other employees with similar duties but less job security, affected many Bureau staffers who were not initially touched by the RIF actions. It was an unhappy time for NBS.

NBS Voice Grows Weaker

Another of President Reagan's economies throttled the Bureau's voice. The employee newsletter, The *NBS Standard,* for a quarter-century the prime means by which employees received news of each other and a significant mechanism used by management to communicate news of administrative changes, was abolished in the name of cost efficiency after publication of the July 22, 1981, issue. It was to be replaced by "regular features or columns from each Commerce agency" in a department publication, *World of Commerce.*

Three months after losing its internal voice, NBS lost *Dimensions/NBS,* the monthly magazine by which the Bureau had communicated with two generations of technical readers worldwide. Begun in 1917 as the *NBS Technical News Bulletin* and continued in 1976 as *Dimensions/NBS,* the magazine offered news of scientific projects written in understandable prose, schedules of meetings of scientific and technical groups, and availability of NBS reports and standards, including Standard Reference Materials. Cessation of the publication was "in line with reduced government spending."

As it did with other economies practiced by the Reagan and other presidential administrations, NBS management played the good soldier with no complaint as two of its communications lines went down. There was no choice in the matter.[35]

Organic-Act Hearings, 1981

The House Subcommittee on Science, Research, and Technology held hearings on the NBS Organic Act on June 16-19, 1981. It was the intention of subcommittee members to review the adequacy of the act that created the Bureau in 1901; drafts of proposed amendments to the 1901 legislation were at hand. Subcommittee member Don Fuqua urged his fellows to take care that any revisions of the Organic Act not deter NBS from useful work on behalf of America. Rep. Douglas Walgren, subcommittee chair, suggested that the relevant question was, "What should the Bureau be doing for the country 5, 10, and 20 years from now?"

[35] John W. Lyons, suffering under the same communications ban during his term as Director, recalled instituting a monthly newsletter to the staff. The size of the newsletter gradually expanded to contain information on activities throughout NIST, thus mitigating the effect of the ban.

During the hearings, Secretary of Commerce Malcolm Baldrige, only months into his new position, gave a ringing endorsement to NBS:

> I view it as one of the best in the world.
> It would be a mistake to alter the mission of the Bureau or otherwise affect its operations by legislation until we have seen what develops from its new relationship to the rest of DoC.

At issue in the hearings were several proposed modifications to the Bureau's environment: a possible new Under Secretary of Commerce for Economic Affairs, who might influence NBS programs; Bureau participation in the work of the International Trade Administration; possible return to NBS of the National Technical Information Service and the Office of Product Standards Policy; and the proper Bureau role in industrial technology development, especially including automation research.

Baldrige stressed his view that NBS should remain primarily a research laboratory, despite its involvement in America's industrial development.

The Malcolm Baldrige National Quality Award

Secretary of Commerce Malcolm Baldrige died in 1987, a victim of his love for riding in rodeos. Friends of Baldrige in Congress, seeking an apt memorial, gave his name to a new suggestion—an award for industrial excellence. Such an award, named for W. Edwards Deming,[36] was given periodically in Japan.

New Commerce Secretary C. William Verity asked NBS to manage the competition for the award.[37] Ambler in turn assigned Curt Reimann to the task. Reimann was a good man for the job, since he had a long-standing interest in quality control and was familiar with the quality-control community in the United States and abroad.

Operating without any special funding, Reimann quickly raised money from the private sector for the project and recruited industrial representatives to develop criteria for the award and to spearhead the selection process.

So effective was Reimann that it became possible to present the first awards on November 14, 1988. President Reagan showed his interest in the concept by his personal participation; Vice President George Bush and several of the Reagan cabinet members also attended the ceremony.

The success of the project led to awards for both Reimann and Ambler—cash for the former, the Secretary of Commerce Medal for the latter.[38]

Management of the Baldrige Quality Award became a continuing function for NIST. Competition for the award became keen among U.S. industrial firms, and NBS

[36] Andrea Gabor, *The man who discovered quality: how W. Edwards Deming brought the quality revolution to America: the stories of Ford, Xerox, and GM* (New York: Times Books/Random House, 1990).

[37] Ambler, *SP 825*, pp. 38-39.

[38] This was the first award of the Secretary's Medal to a government official.

became more secure in the role given it by Congress to "assist industry in the development of technologies and procedures needed to improve quality and modernize manufacturing processes." By 1991 NBS publicists could write:

> The Malcolm Baldrige National Quality Award has quickly become both the U.S. standard of quality achievement in industry and a comprehensive guide to quality improvement. Tens of thousands of U.S. companies are using the application guidelines to evaluate their operations in seven key areas of quality management and performance—leadership, information and analysis, planning, human resource use, quality assurance of products and services, quality results, and customer satisfaction.[39]

Civil Servants by Day, Public Servants by Night

A variety of motives prompted many NBS employees to become active in civic affairs. Some sought an outlet for extra energy, but many more simply saw a need that they could fill on a part-time basis. Both Gaithersburg and its environs and Boulder and its environs offered plenty of opportunity for public service.

It would be very difficult to record all of the instances of public service among Bureau staffers over the years, but it would be unkind to omit some mention of the activity.

Examples of public service during Ernest Ambler's tenure as director included, in Montgomery County, Maryland, home of NBS/Gaithersburg:

- John Menke, Center for Radiation Research, who served on the Montgomery County Council.
- Larry Fischer, Product Performance Engineering Division, who served as a consumer representative for the Washington Suburban Sanitary Commission.
- David Hogben, Statistical Engineering Division, President of the Greater Glen Mill Community Association.
- Donald R. Johnson, Deputy Director, National Measurement Laboratory, member of the Gaithersburg Planning Commission.
- Julius Persensky, Center for Consumer Product Technology, member of the Gaithersburg City Council.
- Gene Rowland, Deputy Director, Center for Mechanical Engineering and Process Technology, member of the Maryland State Advisory Commission for Industrialized Buildings and Mobile Homes.

[39] "Malcolm Baldrige National Quality Award," p. 6 in "Research, Services, Facilities: National Institute of Standards and Technology," *NIST SP 817*, August 1991, 88 pp.

In 1988, exemplars of American industrial excellence began to receive the Malcolm Baldridge National Quality Award, named for deceased Secretary of Commerce Malcolm Baldridge, Jr.

In Boulder County, Colorado, home of the NBS/Boulder Laboratories:

- William L. Gans, Electromagnetic Technology Division, member of the Boulder County Housing Authority.
- John L. Workman, Electromagnetic Fields Division, Mayor of Nederland, Colorado.

Ambler's Impact on NBS

Ernest Ambler was an important figure in the history of NBS. His scientific work gained international renown for himself and the Bureau. He served as chief of the Cryogenic Physics Section and the Inorganic Materials Division, as director of the Institute for Basic Standards, and as Richard Roberts' deputy before commencing a long tenure as Acting Director and Director of NBS. His leadership of the Bureau was instrumental in the transition from NBS to NIST.

Win Some, Lose Some, But Keep On Leaning

Ernest Ambler directed the work of the National Bureau of Standards for nearly 14 years, longer than any save Samuel Stratton and Allen Astin. It can be argued that Stratton's administration of the Bureau was the most tumultuous—he personally carried the nascent agency through its infancy, successfully and continually marshalling new congressional support in order that NBS could undertake new and needed projects. It can also be argued that Astin personally brought the Bureau through a perilous time, overseeing the dispersal of one-third of its war-time staff to other agencies, seeing his agency pilloried as unfair to American enterprise, and finding himself called upon to resign, only to leave his post years later of his own volition with the reputation of NBS at an all-time high. But one can make a case that Ambler, too, brought his agency through a decisive period of its existence.

Heavy pressure on NBS during Ambler's tenure as director came from two sources. From the administrations of Presidents Carter and Reagan—both innately suspicious of big government and both determined to prune it—came calls for the privatization of the national standards of measurement; for abandonment of the postdoctoral research associate program; for disposal of the NBS fire program, its building-technology program, its library, its Personnel Division, its Instrument Shops, its NBS procurement group; and for an end to publication of the *Journal of Research*, the *NBS Dimensions* magazine, and the *NBS Standard*. From the Congress came ever-louder urging for the Bureau to do more for cooperative technology, industrial productivity, technology transfer, international competitiveness—many names for the same idea.

Ambler intuitively resisted administration attempts to weaken NBS; the threat to its postdoctoral program he found especially dangerous. Some of those battles he won, some he lost. But Ambler had learned one lesson well during a decade of management at the Bureau—"keep on leaning." He recalled the lesson during a 1991 retrospective speech:[40]

> I did not relish the thought of working with the government machinery outside NBS, but I was prepared to be patient and take it on.
> Above all, you kept coming back and improving your presentation and your own sense of conviction and commitment. "Keep on leaning" became my motto.

[40] E. Ambler, *NBS Special Publication 825*, April 1992, p. 32.

On the other hand, Congressional calls for NBS to assist American industry struck a responsive chord in Ambler early in his tour as director. Here was a niche that offered an expanding future for the Bureau.

Leaning Towards Industrial Productivity

In a revealing preface to a report on progress at NBS during 1979 and 1980, Ernest Ambler wrote:[41]

> I would like to focus for a moment on the future, and on how NBS research can help find solutions to this country's most important and complex problems. Energy, environment, health, public safety are quite familiar. Relatively new challenges with equally important consequences for our standard of living and general economic strength are the needs for improved industrial innovation and productivity.

In the introduction to that report, the following statement appeared:

> During 1980 every effort has been made to tailor the research programs of (NBS) to the technology needs of the coming decade.

The text continued with a brief discussion of the effort to maintain and enhance both the NBS facilities and its staff in the fundamental areas of science and engineering that were seen as vital to coming national needs. Then it directed the reader's attention to projects intended to "bolster industrial productivity while encouraging energy conservation"—electronics, automation, chemical processing, and advanced materials. These new watchwords began to dominate the language of Bureau management during the decade of the 1980s.

In a 1991 discussion of his administration, Ambler dwelt at length on his personal reaction to the 1982 *Packard Report*.[42] He was much taken with the recommendations of the report, particularly the first, calling for a "well-defined agency mission," and the fifth, calling for "stronger interactions with academia and industry." These, he felt, fit well with the mandates continually pressed on the Bureau by members of congress. He gave particular significance to refining the NBS mission with regard to assisting U.S. industrial prowess, to strengthening ties with outside organizations, and placing more emphasis on outside review of NBS work. During the 1980s, that approach was successful in attracting increasing financial support from other government agencies and from users of NBS services.

As time went on, Ambler saw more and more clearly the significance of the push toward industrial productivity that was manifest in both the Congress and in Reagan's Commerce Department.

[41] "National Bureau of Standards 1980," *NBS Special Publication 600*, January 1981, 40 pp.

[42] Ambler, *NBS Special Publication 825*, pp. 33-34.

By 1988, Ambler saw the transformation of the National Bureau of Standards into the National Institute of Standards and Technology not as a threat, but as an opportunity. He was convinced that intimate involvement by a strong technical agency in solving America's trade deficit would happen—if not by NBS, then by another agency taking its place. Shortly after his retirement, Ambler described the Congressional attitude on passage of the 1988 Competitiveness Act:[43]

> The intent was clear to have NIST "assist industry." Also implicit [was that] this new function should receive equal if not greater emphasis than that of providing basic standards and measurements.
>
> Congress wanted to expand our vision, our influence, and our funding and help us achieve our full potential in the way we worked with industry, small as well as large. To duck such a challenge, even if we could, would not only be faint-hearted, but foolish; we would have become the mother of yet another agency by starving ourselves.

Ambler's attitude towards the place of scientific excellence at NBS was reminiscent of the often-expressed philosophy of Lewis Branscomb. Both men felt that a good scientific atmosphere brought good people to the Bureau, and that good people did good work. Branscomb especially decried the distinction between basic and applied science, preferring to speak of high intellectual content and productivity as the hallmarks of a good staff.

Despite the continuous efforts of the Reagan administration to cut non-military government spending, Ambler left NBS with a substantially larger budget than it had when he took office as director.

TECHNICAL WORK OF THE BUREAU, 1975-1989

Research in Chemistry

Only a few of the many chemistry research projects undertaken by the NBS staff during this period are mentioned in the following pages. However, the accounts serve to underscore the breadth of the Bureau program in chemical science.

Isotopic Enrichment With Lasers

A recurring problem in fields as diverse as clinical medicine and nuclear power was finding ways to obtain chemicals that were enriched in certain isotopes. In medicine and biological research, particular isotopes could be used as tracers to follow the course of chemicals added to living matter. In nuclear power, the radioactive properties of certain uranium isotopes made them especially suitable for use in reactors.

Over the years, various methods were used to achieve isotopic enrichment. A particularly interesting method perfected during this period involved the use of photochemistry. A group of Bureau scientists employed electronic excitation to produce stable, enriched compounds containing chlorine or boron isotopes.

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[43] Ibid., p. 39.

Taking advantage of support from the NBS Laser Chemistry Program, Joseph J. Ritter of the Inorganic Materials Division and Richard A. Keller of the Physical Chemistry Division, along with their colleagues Harry J. Dewey, a postdoctoral research associate in the Optical Physics Division and Michel Lamotte, a visiting scientist from the Faculty of Sciences of Bordeaux, France were able to markedly affect the isotopic composition of ^{35}Cl using a photochemical method.[44]

The authors noted that earlier attempts at enrichment involving laser irradiation had failed to produce stable molecules. One of these attempts had involved Stephen R. Leone, prior to his joining NBS; along with his mentor at the University of California at Berkeley, C. Bradley Moore, Leone had irradiated bromine molecules, using the 558 nm and 532 nm lines from an yttrium-aluminum-garnet laser. The laser irradiation selectively excited the diatomic bromine molecules until they dissociated into atoms that reacted with hydrogen iodide. They found indications that marked isotopic enrichments (from the normal 1:1 ratio of ^{79}Br:^{81}Br to 4:1 $H^{81}Br$:$H^{79}Br$) occurred, prior to "scrambling"—atomic rearrangement of the HBr molecules through collisions, with loss of the enrichment.[45]

Ritter and his colleagues sought to produce stable end-products in their experiments. To this end, they chose to excite ^{35}Cl or ^{37}Cl electrons in thiophosgene ($C^{32}S^{35}Cl_2$ or $C^{32}S^{37}Cl_2$) to a particular state by the choice of the irradiating wavelength of a nitrogen-pumped, tunable dye laser, then to retain the isotopic enrichment by taking advantage of an enhanced chemical reaction rate between the excited molecule and diethoxyethylene. The concentration of ^{35}Cl in thiophosgene was changed from 75 % in the naturally occurring material to 64 % (about one-third the theoretical limit for the concentration change) when ^{35}Cl was selectively irradiated, and from 75 % to 80 % when ^{37}Cl was irradiated.

A similar experiment was performed on boron isotopes by Keller and Samuel M. Freund of the Optical Physics Division, using radiation from a carbon dioxide laser. In this case, boron trichloride was reacted with hydrogen sulfide. After excitation of the ^{11}B–Cl stretching vibration in the BCl_3 molecule for periods as long as 10 hours, the abundance of ^{11}B fell from its usual value of 80.5 % to 70.8 %; correspondingly, the ^{10}B abundance rose from 19.5 % to 29.2 %. Excitation of the ^{10}B–Cl stretching mode, on the other hand, resulted in an isotopic enrichment of ^{11}B.[46]

These experiments led to the issuance of two patents—one for the laser-induced photochemical enrichment of boron isotopes[47] and a second for photochemical enrichment of chlorine isotopes.[48]

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[44] Michel Lamotte, Harry J. Dewey, Richard A. Keller, and Joseph J. Ritter, "Laser induced photochemical enrichment of chlorine isotopes," *Chemical Physics Letters* **30**, No. 2, 165-170 (1975).

[45] Stephen R. Leone and C. Bradley Moore, "Isotopically selective photochemistry of bromine," *Phys. Rev. Lett.*, **33**, No. 5, 269-272 (1974).

[46] "Laser-induced photochemical enrichment of isotopes," *Dimensions/NBS*, April 1975, pp. 80-82.

[47] U.S. Patent 3,996,120, issued December 7, 1976, to S. M. Freund and J. J. Ritter.

[48] U.S. Patent 4,025,406, issued on May 24, 1977, to M. Lamotte, H. J. Dewey, R. A. Keller, and J. J. Ritter.

Later, Ritter made use of the technique to study chemical reactions of the molecules Cl_2CF_2 and Br_2CF_2 with several olefins, finding that he could establish the presence of certain intermediary molecules, as well as determining the levels of enrichment occurring in the isotopes of carbon. Ritter used a carbon dioxide transverse excitation laser in the experiments, which appeared to involve unexpectedly complex free-radical reactions.[49]

Atomic Weights

Lura J. Powell, Thomas J. Murphy, and John W. Gramlich used the technique of mass spectrometry to determine the atomic weight of silver with unprecedented accuracy. The value, 107.868 15 ± 0.000 11, was obtained for the natural isotopic abundance of the element, which contained nearly equal parts ^{107}Ag and ^{109}Ag. The uncertainty of the new determination was smaller than the previous best by a factor of five. To obtain the result for the reference sample, carefully measured quantities of the two isotopes were mixed to calibrate the mass spectrometer.[50]

In their experiments, Powell, Murphy, and Gramlich used the same isotopic samples of silver that had been employed earlier by Richard S. Davis and Vincent E. Bower to improve coulometric measurements of the electrochemical equivalent of silver.[51] Davis and Bower discovered a means of reducing the measurement error arising from impurities in the silver; they dissolved the silver from the residue in the coulometer and plated the silver onto a cathode held at constant potential with respect to a reference electrode, integrating the electrolysis current electronically.[52]

A fundamental units task force of the (international group) CODATA immediately undertook to use the new value for a recalculation of the Faraday, historically evaluated by electrodeposition of silver. The new Faraday uncertainty, reflecting the improved accuracy of the silver atomic weight, improved by a factor of five.

A discussion of progress in the evaluation of atomic weights and of the use of tables of atomic weights prepared under the auspices of the International Union of Pure and Applied Chemistry was presented by I. Lynus Barnes and H. Steffen Peiser for the National Conference of Standards Laboratories during its 1986 meeting. The authors pointed out the ubiquity of atomic weight data in science, technology and commerce, the usefulness of the IUPAC tables in unifying world-wide data on atomic weights, and the process by which the tabular values were derived.[53]

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[49] J. J. Ritter, "Isotopically selective CO_2 transverse excitation laser induced chemical reactions of Cl_2CF_2 and Br_2CF_2 with olefins," *J. Am. Chem. Soc.* **100**, No. 8, 2441-2444 (1978).

[50] L. J. Powell, T. J. Murphy, and J. W. Gramlich, "The absolute isotopic abundance and atomic weight of a reference sample of silver," *J. Res. NBS* **87**, No. 1, 9-19 (1982).

[51] R. S. Davis and V. E. Bower, "Corrections to the Faraday as determined by means of the silver coulometer," *Atomic Masses and Fundamental Constants*, J. A. Nolen, Jr. and W. Benenson, editors (New York: Plenum Press, 1980), pp. 161-165.

[52] R. S. Davis and V. E. Bower, "A novel method for analyzing silver sediment with high precision," *J. Res. NBS* **84**, No. 2, 157-160 (1979).

[53] I. L. Barnes and H. S. Peiser, "Twenty five years of accuracy assessment of the atomic weights," pp. 22/1-22/10 in *Proc. Natl. Conf. of Stds. Labs., October 6-9, 1986, Gaithersburg, Maryland.*

Quality Control Through Standard Reference Materials

At the July 1979 meeting of the National Conference on Weights and Measures, Donald R. Johnson, programs director for the National Measurement Laboratory, reviewed a few of the many contributions made by the NBS program in Standard Reference Materials (OSRM) to quality control of commercial products. The new chief of the OSRM program was George A. Uriano, a physicist with 10 years' research experience in the Electricity Division, 5 years as Deputy Director of the Institute for Materials Research, and 3 years as Deputy Chief of the OSRM. Uriano succeeded J. Paul Cali as chief; Cali had served in that position for a decade.

Areas singled out by Johnson as particularly benefitting from NBS work included the following:

- Control of the composition of steel, through reference materials and standard procedures. The Bureau offered more than 100 SRMs for steel.
- Identification and measurement of toxic contaminants in food.
- Accuracy in clinical chemistry.
- Development and enforcement of environmental and occupational regulations, which required SRMs for use under the Clean Air Act and the Clean Water Act, as well as for use by the Occupational Safety and Health Administration.
- Measurements of automobile fuel economy.
- Identification and measurement of materials involved in resource recovery programs.

At that time, some 900 Standard Reference Materials in 70 different categories were available from NBS.

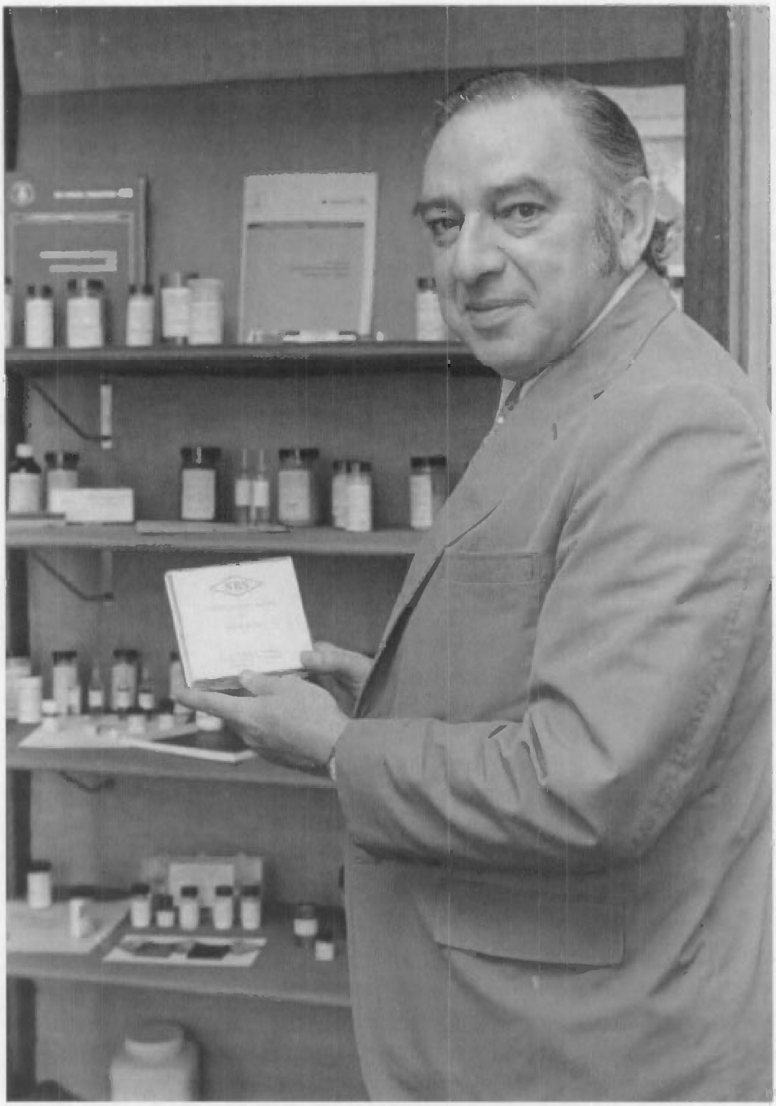
Excitable Chemical Species

Important advances in understanding the effects of radiation on chemical species, as well as the nature of chemical reactions among excited molecules were made at NBS over a long period of time.

Although the Free Radicals program was formally discontinued in July 1959, Bureau work on the chemistry of excited molecules continued in several divisions, owing to the wealth of information to be obtained from such studies.

During 1975, Pierre J. Ausloos, a radiation chemist trained at the University of Louvain, Belgium, and Sharon G. Lias—a Bureau scientist who first visited NBS as a student, then as a Visiting Professor from Rockefeller University in New York City—wrote a textbook on the role of ion-molecule reactions in radiation chemistry.[54] The book was one of a series planned for the U.S. Energy Research and Development Administration.

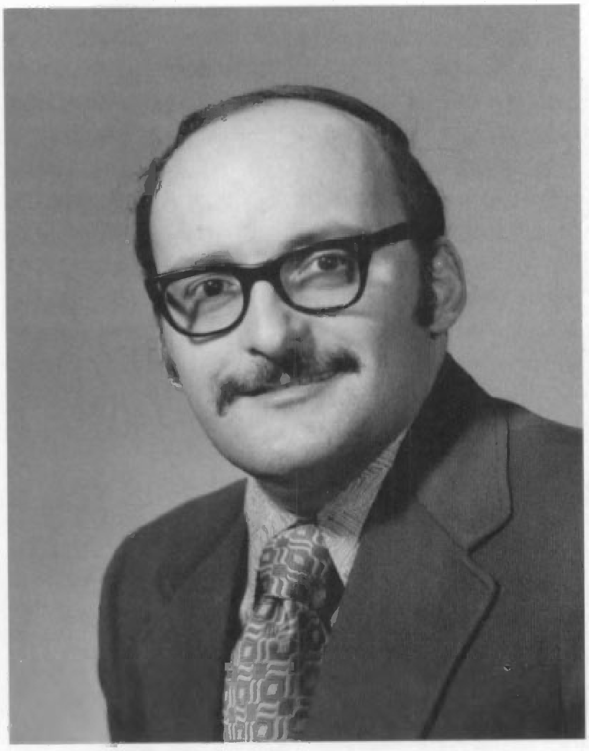
[54] Sharon G. Lias and Pierre Ausloos, *Ion-Molecule Reactions: Their Role in Radiation Chemistry* (Washington, DC: American Chemical Society, 1975) 205 pp.



J. Paul Cali joined NBS in 1966 to manage the production and certification of Standard Reference Materials. He later headed the SRM program until his retirement in 1978.

In a study of the effect of solar radiation on chlorofluorocarbons and carbon tetrachloride, Ausloos, Richard E. Rebbert, and their colleague Lois Glassgow, a guest worker, discovered evidence that even sunlight that had filtered through the earth's atmosphere could dissociate these substances under the right conditions.[55] It was noted

[55] P. Ausloos, R. E. Rebbert, and L. Glassgow, "Photodecomposition of chloromethanes absorbed on silica surfaces," *J. Res. NBS* **82**, No. 1, pp. 1-8, 1977.



George A. Uriano served NBS/NIST in a variety of ways during his 32 years at the Bureau—as a bench scientist, as deputy to the director of the Institute for Materials Research, as chief of the Standard Reference Materials program, and as director of the Advanced Technology program.

by a science writer that the breakdown of halocarbons by solar radiation played a strong role in the durability of the earth's ozone layer.[56]

In recognition of his substantial contributions to excitation chemistry, Ausloos received the Department of Commerce Gold Medal award in 1976. Among the many achievements recorded by Ausloos and his colleagues were numerous experiments; the development of inert-gas lamps, some with special aluminum windows to permit passage of high-energy radiation, to provide radiant sources in the energy range 8 eV to 21 eV; editing of a text on *Fundamental Processes in Radiation Chemistry;* and organizing, for the North Atlantic Treaty Organization Advanced Study Institute, conferences in 1973 and 1974 devoted to the discussion of chemical spectroscopy and photochemistry in the vacuum ultraviolet.

The specialty of Hideo Okabe was ultraviolet photochemistry—especially the study of photodissociation and fluorescence in various types of materials. He evaluated air-pollution aspects of sulfur dioxide (SO_2), developing a detector with a linear response at levels ranging from 20 ppb to 1600 ppm. This work had an immediate impact on the work of the Environmental Protection Agency and industrial firms

[56] *Industrial Research,* April 1977, p. 19.

NBS researcher Albert E. Ledford adjusted an instrument developed at the Bureau to measure very small amounts of ozone, a serious pollutant at ground level but protector against ultraviolet radiation in the upper atmosphere.

engaged in pollution monitoring and control, and it led to the Department of Commerce Gold Medal award for Okabe in 1973.[57] Okabe also investigated the photodissociation of thiophosgene.[58] He also wrote a book, *Photochemistry of Small Molecules,* that became a classic in the field of photochemistry.[59] It was translated into several languages.

Ion-molecule reactions were found to be important in the chemistry of the upper atmosphere of the earth, as well as in excited environments such as flames and plasmas; the reactions were observed in mass-spectrometric studies of the earth's upper atmosphere. Stephen R. Leone, chemist in the Quantum Physics Division and the Joint Institute for Laboratory Astrophysics, developed a new technique for the study of the elusive products of ion-molecule reactions.

Leone and his university colleagues used an infrared detection technique to observe the afterglow in flow of excited helium gas carrying negatively charged oxygen atoms, which reacted with carbon monoxide in a flow tube. Vibrational chemiluminescence was observed from the carbon dioxide molecules formed by the ion-molecule reaction; it was the first such observation reported. The group found evidence of vibrational excitation in the CO_2 spectrum, and they obtained to obtain information on the dynamics of the reactions and on the rates of energy loss from the excited vibrational states.[60]

Calorimetry, a Basic Tool for Chemists

Calorimetry, the experimental determination of the heat content of materials, was a basic tool for chemists from the earliest days of the study of chemistry. Yielding information about the thermodynamic properties of a test substance and about the thermal changes occurring in chemical reactions, calorimetry provided essential guidance for the chemist and the chemical engineer.

Since it was an important science, the study of calorimetry was a continuing program from the beginning of NBS. By the year 1911, the Bureau already was supplying about 100 types of combustion samples for use in the calibration of calorimeters.[61] These calibration samples were extremely valuable to calorimetrists because each of their measurements was performed in a home-made instrument.

In 1946, a meeting of a group of low-temperature calorimetrists was organized by Hugh M. Huffman, a scientist at the Bureau of Mines in Bartlesville Oklahoma, in conjunction with a meeting of the American Chemical Society. The meeting was sponsored by the Committee on Thermal Data for the Chemical Industry, an arm of the National Research Council.

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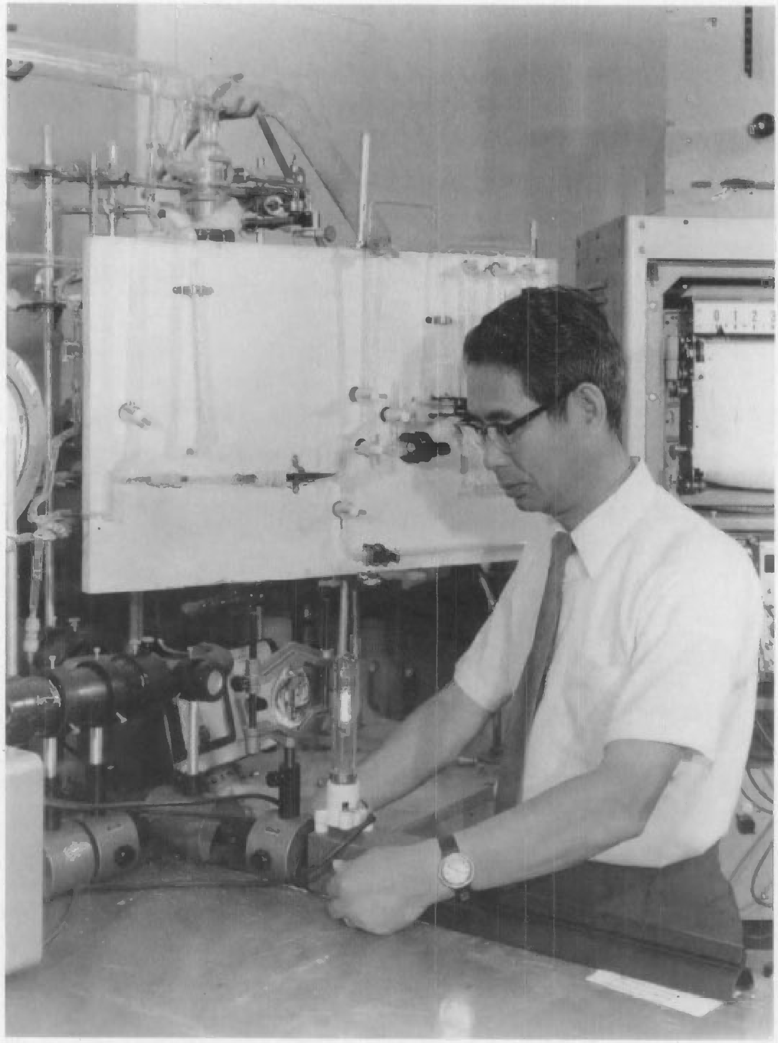
[57] H. Okabe, "Fluorescence quenching of sulfur dioxide by source emission gases," *Anal. Chem.* **48**, No. 11, 1487-1489 (1976).

[58] H. Okabe, "Photodissociation of phosgene," *J. Chem. Phys.* **66**, No. 5, 2058-2062 (1977).

[59] Hideo Okabe, *Photochemistry of Small Molecules* (New York: Wiley-Interscience, 1978).

[60] V. M. Bierbaum, G. B. Ellison, J. H. Futrell, and S. R. Leone, "Vibrational chemiluminescence from ion-molecule reactions: $O^- + CO = CO_2 + e^-$," *J. Chem. Phys. Lett.* **67**, No. 5, 2375-2376 (1977).

[61] NBS Annual Report for 1911, p. 80.



In work that was recognized by the Gold Medal Award from the Department of Commerce, chemist Hideo Okabe developed a sulfur dioxide monitor. Here, he was shown adjusting the apparatus.

The opportunity for calorimetrists to meet regularly with other scientists who shared their concerns so captivated them that they immediately made the calorimetry meeting an annual event called the Calorimetry Conference. It was decided quickly that conference topics should include high temperatures as well as low. Attendance at the conferences grew from 40 in 1947 to as many as 200 during the 1980s.

Gradually, a loose structure for the conferences was formed by members in academia, in industry, and in government. Eventually, each conference elected officers including a chair, a treasurer, a Board of Directors, and Counselors. The Bureau was involved in the Calorimetry Conferences from the start. Ferdinand G. Brickwedde and Russell B. Scott were among only 14 scientists who attended the first meeting.[62]

The expressed intention from the beginning of the conferences was to cater to scientists actively practicing thermal measurements. The primary focus of the first meeting was on accuracy of measurements. Necessarily, that topic included an emphasis on the accuracy of the temperature scale and on the quality of available thermometers.

Hugh Huffman died in 1950; 4 years later an award for excellence in calorimetry research was created in his name. Brickwedde was the second scientist to receive the Huffman Award. Other NBS winners of the award included Frederick D. Rossini, in 1956; Charles W. Beckett, in 1967; and Edward J. Prosen, in 1979.

Many Bureau staff members were involved in administering the conferences.[63] These include service as:

- Conference Chair: Prosen (1954), George T. Armstrong (1964), E. Dale West (1971), Patrick A. G. O'Hare (1985), Jane E. Callanan (1989), and Eugene S. Domalski (1995).
- Secretary-Treasurer: George T. Furukawa (1961-63).
- Members of the Board of Directors: George T. Furukawa (1956, 1966, and 1973), Armstrong (1961), West (1967), Prosen (1968), Robert N. Goldberg (1974 and 1993), Kenneth L. Churney (1976), Callanan (1983), Duane R. Kirklin (1986), Jennifer C. Colbert (1989), and Yadu B. Tewari (1992).
- Counselors: Armstrong (1979-80), Callanan (1985-86), and Domalski (1988-92).

Brief notes describing the Bureau's Huffman Award winners and members of the Bureau staff who chaired various conferences provides a precis of NBS activities in calorimetry:

- Some of Brickwedde's accomplishments—producing the first measurable quantities of deuterium for Professor Harold Urey, and helping to create equipment for the liquefaction of liquid hydrogen in record quantities—have been chronicled earlier in this volume. His 30-year career at NBS also included thermodynamic studies of hydrogen and deuterium and a variety of thermometry and calorimetry work. He received the Department of Commerce Gold Medal in 1953. Brickwedde served as Chief of the NBS Low Temperature Laboratory from 1926-46 and as Chief of the Heat and Power Division from 1945-56.

[62] R. M. Izatt, P. R. Brown, and J. L. Oscarson, "The history of the Calorimetry Conference: 1946-1995," *J. Chem. Thermodynamics* **27**, No. 5, pp. 449-464 (1995).

[63] Eugene S. Domalski, Private communication. Much of the information contained in this section was kindly provided by Domalski.

- Rossini was a Bureau staff member from 1928 to 1950. He served for more than a decade on the Commission on Thermochemistry of the International Union of Pure and Applied Chemistry—5 years as its Chair. He built calorimeters for use in the study of the enthalpy of reaction of hydrogen and oxygen and also to measure the heat of combustion of methane and many other hydrocarbons. Besides some 200 scientific papers, Rossini was the author of 11 books. In 1942, he accepted the directorship of a project of the American Petroleum Institute—*Project 44,* the collection, calculation and compilation of a great variety of data of interest to the petroleum industry. His greatest legacy was *NBS Circular 500,* "Selected Values of Chemical Thermodynamic Properties." It became a valued reference for chemists and chemical engineers.

- Charles Beckett joined NBS as a research chemist in 1950. He soon became Chief of the Thermodynamics Section of the Heat and Power Division. His scientific work, in the course of which he received the Department of Commerce Gold Medal Award, was achieved despite the effects of severe arthritis. He performed research in mass spectrometry, shock-tube studies, flame, drop, and bomb calorimetry, statistical mechanics, molecular and microwave spectroscopy, and high-speed thermodynamic measurements.

  Later, Beckett agreed to serve as Project Coordinator for an Air Force rocketry program to derive thermodynamic information on light elements. During the 1960s and 1970s, thermal-properties research of national importance was performed in the Heat Division by Joseph F. Masi, Beckett, Armstrong, and others under contract with the U.S. Army and the U.S. Air Force. Many NBS staff members contributed scientific work to this project over a period of several years. Beckett also edited the NBS Journal of Research from 1962-75.

  Upon Beckett's retirement from NBS in 1976, a symposium on the topic of chemical thermodynamics was held in his honor.

- Edward Prosen came to NBS in 1936, before completing his formal training in science. His initial position was that of an assistant in physics. During his nearly 45 years at the Bureau, he became known internationally for his work in thermodynamics, hydrocarbon bomb calorimetry and the reactions of boron compounds. He was a member of the International Union of Pure and Applied Chemistry (IUPAC) Commission on Thermodynamics. He won the Department of Commerce Gold Medal Award in 1956.

  As late as 1977, Prosen participated in a microcalorimetric study of heart pacemakers, a project intended to assess the feasibility of using that method to measure energy loss in the cardiac devices in a nondestructive manner.[64]

- A transplanted Irishman, Patrick A. G. O'Hare spent most of his scientific career in physical chemistry research at the Argonne National Laboratory. He joined NIST in 1989. His principal calorimetric interests lay in bomb calorimetry, where he studied fluorides, selenides, silicides, and tellurides.

[64] E. J. Prosen and J. C. Colbert, "Microcalorimetric study of cardiac pacemakers," *NBSIR 77-1310,* September 1977, 21 pp.

- George T. Armstrong came to NBS from Yale University in 1951 as a member of the Heat and Power Division. His early work focused on the vapor pressures of fuels and other high-energy substances.[65] By the early 1960s he directed the Combustion Calorimetry Laboratory in the division's Heat Measurements Section, with responsibility for creating techniques and standards of heats of combustion. He developed a special interest there in fluorine thermochemistry, for which he received the Department of Commerce Silver Medal Award in 1967.[66]
- E. Dale West joined NBS in 1948. His principal interests at the Bureau were in adiabatic calorimetry at high temperatures. He studied the heat capacity, transition temperatures and heats of transition in sulfur and made similar measurements in sapphire and graphite. West headed the Heat Measurements Section of the Heat Division for 2 years, then transferred to Boulder, where he headed the Laser Radiometry Section of the Quantum Electronics Division. There he developed a reference calorimeter for the measurement of laser power. He retired from NBS in 1980 to create a company for the commercial design and construction of calorimeters.
- Jane E. Callanan came to NBS in 1981 as a research chemist. Her research interests were varied: low temperature heat capacity, standards for differential scanning calorimetry, thermal characterization, and thermodynamic properties. She left the Bureau in 1991 to establish a consulting firm in Boulder, Colorado.
- Eugene S. Domalski joined NBS early in 1959 as a member of the Heat Measurements Section of the Heat Division. Soon he began collaborating with George Armstrong in studies of heats of formation and heats of combustion. Later he took an active role in preparing thermodynamic data, including two definitive compilations of heat capacity of organic compounds, for the Office of Standard Reference Data, and in the calorimetry of refuse-derived fuels for the energy-conservation program.

Discussion of the Bureau's activities in calorimetry would be incomplete without acknowledgment of the large role played by George T. Furukawa and his associates. Furukawa joined NBS in 1949 as a member of the Thermodynamics Section of the Heat and Power Division. Ferdinand G. Brickwedde was chief of both the section and the division at that time. Furukawa's considerable ability as a calorimetrist was directed immediately to providing calorimetric data of interest to the members of the Calorimetry Conference. With his colleagues Defoe C. Ginnings, Robert E. McCoskey, Raymond A. Nelson, Gerard J. King, Martin L. Reilly, Thomas B. Douglas, Anne F. Ball, Jeanette H. Piccirelli, William G. Saba, and Andrew C. Victor, Furukawa furnished calorimetric properties data on a succession of materials intended for use as standard samples dedicated to the purposes of the Calorimetry Conference.

[65] George T. Armstrong, F. G. Brickwedde, and R. B. Scott, "The vapor pressure of the deuteromethanes," *J. Chem. Phys.* **21**, 1297 (1953).

[66] E. S. Domalski and G. T. Armstrong, "The heats of combustion of polytetrafluoroethylene (Teflon) and graphite in elemental fluorine," *J. Res. NBS* **71A** No. 2, 105-118 (1967).

When the Heat Measurements Section of the Heat Division was disbanded in 1970, Furukawa transferred his attention to more specifically thermometric problems with the same characteristic thoroughness he had earlier given to calorimetry.

New Equations for Steam

Steam, one of man's oldest sources of motive power and a key ingredient in many manufacturing processes, would seem an unlikely prospect for an NBS investigation. Yet Lester Haar and John S. Gallagher of the NBS Thermophysics Division and George S. Kell, a colleague from the National Research Council in Ottawa, Canada undertook the task of re-formulating the equations that provided thermodynamic properties for water and steam.

The work was requested by the International Association for the Properties of Steam and performed under the auspices of the National Research Council of Canada (NRC) and the Bureau's Office of Standard Reference Data. The three scientists prepared new equations to cover the temperature range from 0 °C to 2000 °C and the pressure range from 0 GPa to 3 GPa (about 30,000 times atmospheric pressure).

Demand for the new tables, entitled "NBS/NRC Steam Tables: Thermodynamic and Transport Properties and Computer Programs for the Vapor and Liquid States of Water in SI Units" was sufficiently large that the Hemisphere Publication Corporation of Washington, DC printed the tables in book form.[67]

The new tables quickly became a "best seller" among NBS reports. Demand remained brisk for more than a decade.

A Hectic Decade for NBS Fire Science

Following release of "America Burning," a dramatic report issued in 1973 by the National Commission on Fire Prevention, the Nation's efforts in fire protection received more attention. In brief, the report indicted the United States as possessing the worst record for fire deaths and property loss of any of the major industrial nations. Enactment of the *Federal Fire Prevention and Control Act of 1974* soon followed.

The following account is lengthy, primarily to portray a coherent picture of a large Bureau program—fire science—over a long period of time. The account also illustrates well the level of dedication that came from a group whose very existence was questioned at the highest executive levels.

An NBS Center for Fire Research

By direct instruction of the *Federal Fire Prevention and Control Act of 1974,*[68] the Bureau created a Center for Fire Research, "to conduct basic and applied fire research, research into the factors influencing human victims of fire, and operation tests, demonstration projects, and fire investigations."

[67] L. Haar, J. S. Gallagher, and G. S. Kell, "*NBS/NRC Steam Tables: Thermodynamic and Transport Properties and Computer Programs for the Vapor and Liquid States of Water in SI Units*" (Washington, DC: Hemisphere Publication Corporation, 1984) 320 pp.

[68] Public Law PL93-498, 88 Stat. 1535-1549, enacted October 29, 1974.

As we noted in chapter 3, Director of the new center was John Lyons, hired by Director Richard Roberts in October, 1973 to give new leadership to the entire program of fire research at NBS. By September, 1975, Lyons had in place his senior management team.

Heading the Fire Science Division was Robert S. Levine, newly arrived from NASA's Langley Research Center with experience in rocket technology. The division's program for physics and dynamics was led by John A. Rockett, an experienced fire hand who had joined the Bureau in 1968 to plan for the implementation of the *Fire Research and Safety Act of 1968*. The division's program for fire chemistry was headed by Clayton M. Huggett, who since 1970 had supervised research on the chemistry of ignition and combustion, fire retardants, and the toxicity of combustion products. Acting Director of the program for toxicology of combustion products was Merritt M. Birky, a 1961 NAS/NRC postdoctoral research associate in chemical thermodynamics with 7 years' subsequent experience in atomic physics and 4 years with the fire science program. Acting chief of the Office of Information and Hazard Analysis was Benjamin Buchbinder.

The Fire Safety Engineering Division was headed by Irwin A. Benjamin, a structural engineer who joined NBS in 1968 as Chief of the Fire Research Section of the Building Research Division. Studies of fire prevention were headed by James H. Winger—since his entry to NBS in 1971 heavily involved in the development and evaluation of fire test methods. A program in control of fire in furnishings was led by Sanford Davis, newly arrived from the BASF Wyandotte Corp. A project in fire design concepts was headed by Harold E. Nelson. Acting chief for control of fire in construction was Daniel Gross, since 1950 involved at NBS in various aspects of fire research. Acting chief of a program in fire detection and control systems was Richard G. Bright.

By the end of 1974, the NBS fire program had stopped using test facilities at the former Bureau site in Washington, DC. The Fire Research building at Gaithersburg, begun in October 1973, was occupied in April 1974, dedicated on June 25, 1974, but completed only during October 1975. The building was located somewhat away from the general-purpose laboratories for improved safety. With forward-looking management at all levels, the program was well into its most productive era, but one that would not be free of controversy.

Topsy-Turvy Funding

The Center for Fire Research was staffed by 90 full-time permanent employees during 1974. This staff was augmented by perhaps 20 Industrial Research Associates, postdoctoral research associates, and guest scientists. They worked with great effectiveness on a variety of projects, as we shall soon see. However, funding for the new center was very much out of the ordinary, mainly because of repeated changes in the administration of the Nation's fire programs.

A chronological treatment of the House Appropriations Commerce Subcommittee may best illustrate the uneven support that the funding process produced for the NBS fire program:

- **Date: April 9, 1974**

Hearings on National Bureau of Fire Prevention.[69]
Testimony given by: Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology and John W. Lyons, Director, NBS Fire Programs.

At the time of these hearings by the 93rd Congress in its second session, authorizing legislation for a *National Bureau of Fire Prevention* had passed the Senate and was awaiting floor action in the House. Assuming that the NBFP would come to exist, the Subcommittee intended to fund its planned $4 million budget from two sources: the *National Science Foundation* which, through its program on "Research Applied to National Needs," would contribute $1.7 million; and NBS, which would contribute $3 million from its fire program. The Subcommittee's uncertainty regarding the future of the Bureau's fire research program can be detected in the following exchange:

> Mr. Slack: Do you or do you not propose to have the National Bureau of Standards continue its program with your reimbursing them for their work?
> Dr. Ancker-Johnson: Yes, Sir, NBS will continue work with the $3 million in programs transferred to the new Bureau. At this time, we intend to do no research in-house. We will use the National Bureau of Standards facilities.

As she had done the previous year, Ancker-Johnson presented the NBS budget as a part of a larger "Science and Technology" activity. During that presentation, the NBS fire program was discussed only briefly:

> Mr. Slack: What fire research work would remain as part of your regular appropriation in NBS?
> Dr. Ancker-Johnson: In Fiscal Year 1975, Mr. Chairman, there will be a base program funded at a level of $1,181,000.[70]

- **Date: October 29, 1974**

Federal Fire Prevention and Control Act of 1974

The FFPCA-74 created new agencies for fire prevention and research, but the *Bureau of Fire Prevention* was not among them. Instead, the act established a *National Fire Prevention and Control Administration* as part of the Department of Commerce and a *Fire Research Center* as part of NBS. Joseph E. Clark, former chief of the Bureau's Fire Technology Division, was named Acting Administrator of the NFPCA. The NFPCA was authorized $10 million for the Fiscal Year ending June 30, 1975, and $15 million for the fiscal year ending June 30, 1976. The NBS Fire Research Center (as the Act called it) was authorized $3.5 million and $4 million for the same periods.

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[69] House Appropriations Subcommittee hearings, Part 3, Commerce, pp. 824-845.

[70] Ibid., p. 1008.

- **Date: April 15, 1975**

Hearings on Fiscal 1976, House Appropriations Subcommittee on Commerce:

A. National Fire Prevention and Control Administration.[71] Testimony of Joseph E. Clark, Acting Administrator, NFPCA:

The $3 million from the NBS Fiscal 1975 funding that was to have gone to the Bureau of Fire Prevention instead went to the NFPCA and thence back to NBS in reimbursement for services rendered. In his general statement, Clark observed:

> The 1975 (NFPCA) budget included a transfer of $1.7 million from the NSF. . . RANN program. . . and a transfer of $3 million from the NBS fire research and safety program. In 1976, the remaining $1.1 million of the NBS fire research and safety program is being transferred to the NFPCA to consolidate all Commerce fire programs within one appropriation. The Fire Research Center located at the NBS Gaithersburg, MD, facilities will be funded on a reimbursable basis by the NFPCA.[72]

Carrying out the plan outlined by Clark would place the entire NBS program in fire research under the direction of another agency. The Bureau had fought this type of problem earlier—Allen Astin had struggled during the post-WWII period to bring the fraction of direct congressional funding for NBS from 40 % to a more livable 80 %. To have an entire Bureau center under outside control—no matter the level of communication with the outside agency—would rob the Bureau of its ability to direct its own work.

Mr. Slack displayed his puzzlement about the Commerce Department intentions in the following exchange:

> Mr. Slack: Is the Fire Research Center a separate organization?
> Mr. Clark: The legislation established a Fire Research Center in a formal sense as a separate entity.
> Mr. Slack: Would you tell us about the proposed transfer of this $1.1 million from NBS?
> Mr. Clark: The transfer of $1.1 million in 1976 from NBS to the Fire Administration is for the purpose of consolidating in one appropriation all of the Commerce Department fire programs.[73]

B. The NBS Fire Research Center

Director Richard Roberts, testifying on behalf of NBS, submitted a detailed budget for the Bureau that showed[74] the loss of $3 million in fire-research base funding for Fiscal 1975, and the plan to transfer the remaining $1 million base support for fire

[71] Ibid., pp. 301-367.

[72] Ibid., p. 335.

[73] Ibid., p. 364.

[74] Ibid., p. 470.

research in Fiscal 1976. This plan was repeated in his discussion with Congressman Joseph D. Early of Massachusetts.

> Mr. Early: So in two transactions we are transferring $3.2 million [originally in the NBS budget] from the National Fire Prevention and Control Administration, and in another section of this request we are transferring $1.1 million from NBS?
> Mr. Roberts: That is correct, sir. We decided in the Department of Commerce that it would make more sense to budget all of the dollars in one place.[75]

Congressman Early, perhaps not sure he was hearing the story correctly, asked Roberts to repeat it. Roberts did.

In the House hearings through Fiscal 1979, there is no evidence of base-funding support for the NBS Center for Fire Research. All of the support came from outside, mostly (about $4 million to $5 million) from the National Fire Prevention and Control Administration.[76]

- **Date: February 28, 1979**

Hearings of Fiscal 1980, 96th Congress, House Appropriations Subcommittee on Commerce.

During the hearings for Fiscal Year 1980, Jordan J. Baruch, Assistant Secretary of Commerce for Science and Technology under President Jimmy Carter, presented the NBS budget as had his immediate predecessor. Baruch sought to reverse the funds transfer that had taken place years before.[77]

> Mr. Slack: I note that you propose a transfer of $1.1 million from the U.S. Fire Administration [new name for the National Fire Prevention and Control Administration]. What is the alleged purpose of that transfer?
> Dr. Baruch: The research and development activity at the bureau in fundamental effects of fire would be moved out of the Federal Energy Emergency Management Association directly to the bureau [NBS]. The $1.1 million is dictated primarily by some needs for basic fire research.
> Mr. Slack: If you can, tell me again why would we not transfer all of the funds for fire research to NBS?
> Dr. Baruch: Good question.

As the Fiscal 1980 NBS appropriations bill was enacted, it included the restoration of $1.1 million for its basic work in fire research. Direct Congressional funding for the NBS fire science program was back. The funding level stayed near $1.2 million for

[75] Ibid., p. 689.

[76] House hearings, March 10, 1978, p. 631.

[77] House hearings, February 28, 1979, pp. 630-633.

several years; then in 1982, Director Ambler suggested[78] that certain funds appropriated for the Federal Emergency Management Agency[79] but customarily earmarked for NBS fire research be transferred to the Bureau's Fiscal 1983 budget. Remarkably, this change was made—the fire program received more than $5 million.

Any joy in the Center for Fire Research as a result of receiving direct appropriations for most of its program was short-lived. In the next cycle of hearings by the Commerce Subcommittee on Appropriations, it was Ernest Ambler's duty to request that the NBS fire program not be funded at all.[80] Ambler's narrative accompanying the request stated:

> This program is proposed for elimination in support of the [Reagan] Administration's policy of concentrating Federal research activities on fundamental and basic research efforts and on a determination that the research conducted in this program should be undertaken by the private sector.

The Center for Building Technology was to join the Center for Fire Research in the "Ancient History" file, thus slimming the NBS budget submission by a bit more than $9 million.

At that moment Ambler was in the same tight box that occasionally encloses many a manager. He was constrained by the need to show "team spirit" with the Presidential decision to eliminate programs that industry or state-and-local governments could accomplish; his other option was to resign in protest, a questionable tactic. Despite efforts by Congressman Bernard J. Dwyer, acting chair of the subcommittee, to elicit a murmur of protest from the Bureau director, Ambler hewed to the Administration line. The Congress did not entirely share the President's view; when the Fiscal 1984 appropriation bills were enacted, the fire research program was funded at the level of $5.1 million.[81] The building research funding also survived, at the $3 million level.[82]

The same process of elimination was repeated for the beleaguered building and fire programs as the Administration's Fiscal 1985 budget was presented.[83] Congressman Dwyer left no doubt about his views on eliminating the NBS fire program:[84]

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[78] House Appropriations Subcommittee hearings on Commerce, March 8, 1982, p. 1337.

[79] FEMA was established under President Carter by Reorganization Plan No.3 of 1978 and Executive Orders 12127, April 1, 1979, and 12148, July 15, 1979. The National Fire Prevention and Control Administration was made part of FEMA along with its funding, which included monies previously transferred to NFPCA from the NBS Center for Fire Research.

[80] House Appropriations Subcommittee hearings on Commerce, March 10, 1983, p. 1218, pp. 1287-1290.

[81] House Appropriations Subcommittee hearings on Commerce, March 15, 1984, p. 903.

[82] Ibid., p. 933.

[83] Ibid., p. 943 (building), p. 962 (fire).

[84] Ibid., p. 1029.

Mr. Dwyer: I don't agree with the Administration or whoever recommended the cut of $4 million, to discontinue the research and experiments that go on to try to save lives of people who live in high-rise apartments and in places of public assembly.

It seems to me that this work is most important, because of the new materials that are being developed and installed in these buildings. I think it is really the obligation of the Federal Government to be helpful and useful in that area in protecting these lives.

Once again, the Congress overrode the wishes of the Reagan Administration, funding the fire program for Fiscal 1985 at the level of $5 million.[85]

Prior to the Department of Commerce budget submission for Fiscal 1988 (March 24, 1987), a new strategy for dealing with the NBS fire science program was devised. In this plan, the centers for fire research and building research were combined and their direct appropriation requests pared to reach a total of $5 million. Ultimately, this strategy prevailed, although it appeared to fly in the face of the *Federal Fire Prevention and Control Act of 1974*, which required an administratively separate center for fire research.

Although the staff of the Center for Fire Research might have suffered some nervousness as they watched their appropriations numbers bounce up and down, their productivity during this period was impressive. A rapid search of the excellent facilities of the Fire Research Information Service produced nearly 3000 references to publications by the CFR staff and their colleagues in fire-science programs around the world during the period 1968-1993.

Over the years, the NBS fire program was marked by its wide range of studies—in the theories of fire, in the development of testing devices, and in the examination of actual fire disasters. In the sheer numbers of collaborations with workers in other laboratories and in other disciplines, too, the program set an example for effectiveness.[86]

In the following accounts, we illustrate the breadth of the fire program.

Flammable Fabrics

Public Law 90-189, the Flammable Fabrics Act, amendment of 21967, substantially broadened the responsibilities of NBS.[87] Although these responsibilities declined drastically when the Consumer Product Safety Commission was formed late in 1972, work on fabric flammability continued.

[85] House Appropriations Subcommittee hearings on Commerce, March 6, 1985, p. 1729.

[86] D. Gross, "Fire Research at NBS: The First 75 Years," *Proc. 3rd Intnl Symp. on Fire Safety Sci, July 8-12, 1991, Edinburgh Scotland,* G. Cox and B. Langford, editors (New York: Elsevier Applied Science, 1991), pp. 119-133.

[87] 81 Stat. 568, December 1967.

When the Flammable Fabrics Act amendment was passed, the Bureau got a taste of the life of a regulatory agency; the Congress specified that interstate trade would become illegal for fabrics that could not pass a test devised by NBS. Joseph E. Clark, Chief of the NBS Office of Flammable Fabrics, reviewed the new legal responsibilities of NBS for a textiles periodical.[88] The Bureau, he wrote, was directed to provide the technical underpinning to permit the Secretary of Commerce to define reasonable and useful standards for fabrics, such as rugs, carpets, and clothing. The tools for this work would be flame ignition testing and evaluating the propagation of fire in the fabrics. One of the first fabric standards related to the flammability of children's nightwear. As reported by Emil Braun, James H. Winger, and James A. Slater, garments for children of ages 0 to 12 were chosen because of the relatively high probability of fire-induced injury in that age group. Study of actual fire data showed that fire spread rapidly in such garments, consuming most of the fabric within 30 seconds after ignition. The standard involved the use of a test stand in which the effectiveness of fire retardant could be evaluated.[89]

Refinement of a test cell designed to characterize the chemical and physical properties important to the generation of flash fires in polymeric materials was described by James E. Brown and John J. Comeford in December 1975. The new cell permitted measurement of temperature, geometry, sample orientation and sample size. [90]

After the formation of the Consumer Product Safety Commission (CPSC), NBS was asked to prepare a test that would help minimize the probability of ignition in fabrics and the likelihood of burns. Braun, John F. Krasny, Richard D. Peacock, and Anne K. Stratton reported the development of such a test at the 9th Annual Meeting of the Information Council on Fabric Flammability, held in New York City on December 11, 1975. Called the Mushroom Apparel Flammability Test, it embodied a test stand that approximated real fire accidents, measured real-life hazards, was simple and repeatable, and discriminated between dangerous and safe fabrics.[91]

Braun and his group later investigated the effectiveness of protective clothing worn by fire-fighters, industrial workers, and others whose duties involved exposure to high heat loads. They developed a test stand with which they could apply either radiative or convective heating to a fabric and measure the transmitted heat.[92] Results obtained

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[88] J. E. Clark, "Federal Role in Fabric Flammability Research and Standards," *Textile Information Source and Resources* **4**, No. 4, 7-9, April 1971.

[89] E. Braun, J. H. Winger, and J. A. Slater, "Development of the standards for the flammability of children's sleepwear," in *NBS Special Publication 411; Fire Safety Research, Proceedings of a Symposium at NBS Gaithersburg, August 22, 1973, Mary Jo Butler and James A. Slater, editors,* November 1974, pp. 5-15.

[90] J. E. Brown and J. J. Comeford, "Technique for the measurement of flash fire potential of polymeric materials," *NBSIR 75-757,* December 1975, 32 pp.

[91] E. Braun, J. F. Krasny, R. D. Peacock, and A. Stratton, *NBS Activities in Apparel Flammability,* (Galveston Texas; Information Council of Fabric Flammability, 1975, 317 pp.) pp. 263-277.

[92] E. Braun, D. Cobb, V. B. Cobble, J. F. Krasny, and R. D. Peacock, "Measurement of the protective value of apparel fabrics in a fire environment," *Journal of Consumer Product Flammability* **7**, No. 1, pp. 15-25, March 1980.

with the new test stand as reported by John Krasny became part of a Special Technical Publication published by the American Society for Testing and Materials. Krasny noted the requirements of protective clothing—the fabric should not ignite, shrink, melt, or become brittle, yet it should insulate the wearer against external heat without inhibiting bodily motion. Seven types of fabric were tested in the study, including aramid, fire-retardant cotton, modacrylic, polyester, and wool. In general, 15-45 seconds of protection against injury were provided by a single layer of any of the fabrics.[93]

The CPSC continued to fund fire-research projects at NBS for some time.

An excellent tool used to evaluate specimen flammability was called the cone calorimeter. Vytenis Babrauskas, a versatile fire-protection engineer, who came to NBS in 1977, developed the cone calorimeter in collaboration with William H. Twilley. Babrauskas also undertook the combustion calorimetry of furnishings, fire modeling, and test procedures. The cone calorimeter employed a load cell for automatically recording the changing mass of the specimen during the test, ignition by either spark or radiation, and monitors for released gases and smoke. Liquid, solid, or composite samples could be accommodated in either a vertical or a horizontal position. The cone calorimeter was chosen by Research and Development magazine for its R&D 100 award in 1988.[94]

James Brown, Emil Braun, and William H. Twilley used the cone calorimeter to evaluate U.S. Navy ship components made of synthetic resins or composites of fiber-reinforced resins, often chosen for light weight or non-magnetic properties. They were able to derive indicators for five material parameters: the amount of radiant flux necessary to produce ignition within a preset time; burn intensity as a function of heat load; propensity to continue burning; yields of gaseous pyrolytic products; and the average area of extinction.[95]

Laboratory Work in Fire Fundamentals

Atomic and Molecular Studies

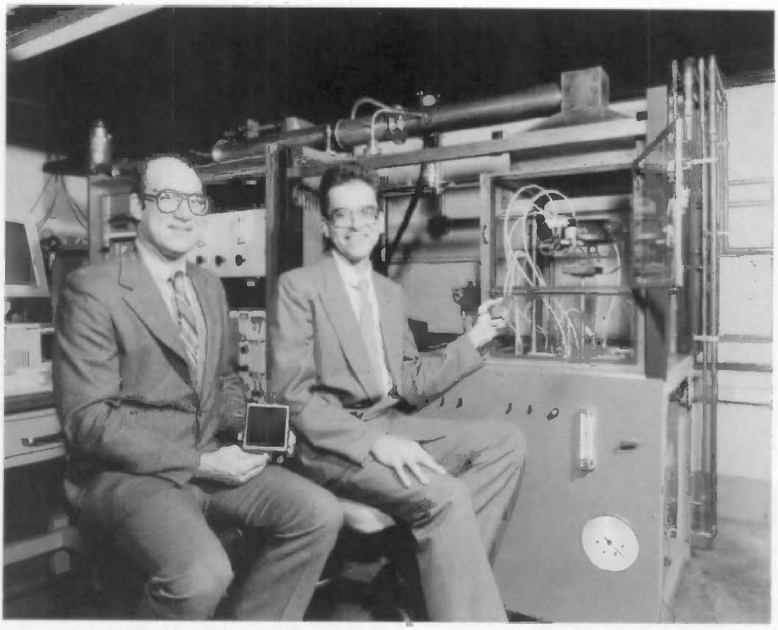
One of the earlier projects in the fundamentals of fire science was initiated by a scientist from another laboratory—John W. Hastie, a flame spectroscopist who worked in the Inorganic Materials Division. Hastie prepared a detailed discussion of fire retardants from the point of view of molecular reactivity. He considered well-known retardants that contained antimony, phosphorus, and halogens. It appeared that these compounds acted as *radical traps* in the preflame or reaction zones. He pointed out the need for thermochemical and reaction kinetics data, as well as rates of vaporization.[96]

[93] J. F. Krasny, "Some characteristics of fabrics for heat protective garments," *ASTM STP 900,* R. L. Barker and G. C. Coletta, editors, (Philadelphia: ASTM, 1986) pp. 463-474.

[94] V. Brabrauskas, "The cone calorimeter, a new tool for fire safety engineering," *ASTM Standardization News* **18**, No. 1, pp. 32-35, January 1990.

[95] J. E. Brown, E. Braun, and W. H. Twilley, "Cone calorimeter evaluation of the flammability of composite materials," *NBSIR 88- 3733,* March 1988, 61 pp.

[96] J. W. Hastie, "Molecular basis of flame inhibition," *J Res NBS* **77A**, No. 6, 733-754 (1973).



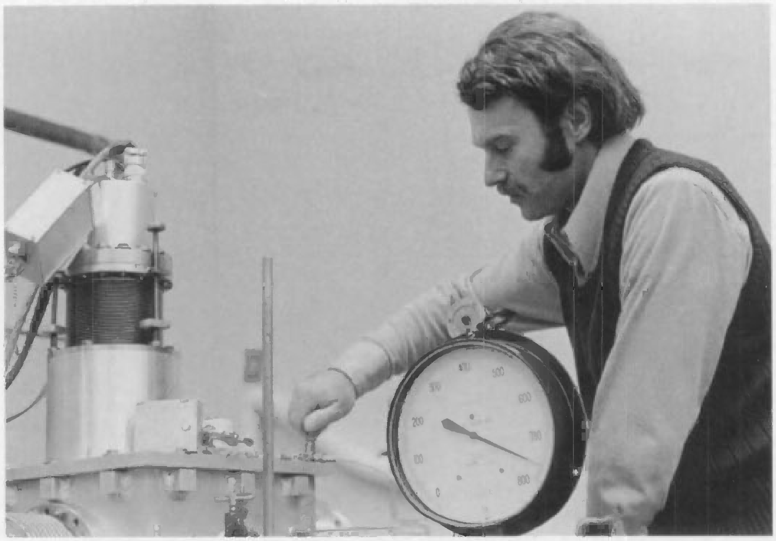
William H. Twilley (left) and Vytenis Babrauskas with the cone calorimeter that they developed. The cone calorimeter, which won an IR-100 Award from *Industrial and Research and Development* magazine, provided data critical to predicting the fire hazard of a product from a small sample of its material.

Later, collaborating with David W. Bonnell of the Inorganic Materials Division, Hastie developed "a new thermochemical tool"—transpiration mass spectrometry—to sample high-temperature gases and vapors.[97] The two scientists had overcome traditional limitations associated with classical vaporization methods. The new method did not require the use of low pressures, and it permitted positive identification of transport molecules. They found that use of the new instrument permitted them to sample reactive gases at temperatures as high as 1500 °C and pressures as high as 1 MPa (10 atmospheres), with little or no loss of accuracy in resulting thermochemical data.

The transpiration mass spectrometer was selected for an IR-100 award as one of the best technical developments of 1980.

An interdivisional team of scientists—Ilan Chabay of the Analytical Chemistry Division, Gregory J. Rosasco of the Inorganic Materials Division, and Takashi Kashiwagi of the Fire Science Division—developed a method of using fast-Fourier transforms of Raman signals from pollutant gases in turbulent air streams. For

[97] J. W. Hastie and D. W. Bonnell, "Transpiration mass spectrometry—a new thermochemical tool," pp. 183-233 in *Thermochemistry and Its Applications to Chemical and Biochemical Systems*, M. A. V. Ribeiro da Silva, Editor (D. Reidel Publishing Company, 1984).



John W. Hastie of the Bureau's Inorganic Materials Division adjusted the pressure in a flame-sampling mass spectrometer prior to observation of species involved in flame inhibition.

illustrative purposes, they tracked methane as an impurity in air, measuring the average concentration, its change with time, and its change with frequency. The measurements could be recorded for different positions with respect to the apparatus. The method was expected to prove useful in studies of smoke and fire.[98]

A method for tracking ions and neutral species by the opto-galvanic effect was presented by Peter Schenck. He found that when an atomic species in an electrical discharge was irradiated at a wavelength sufficiently low to cause an electronic transition, an easily detectable voltage signal arose because of the absorption.[99]

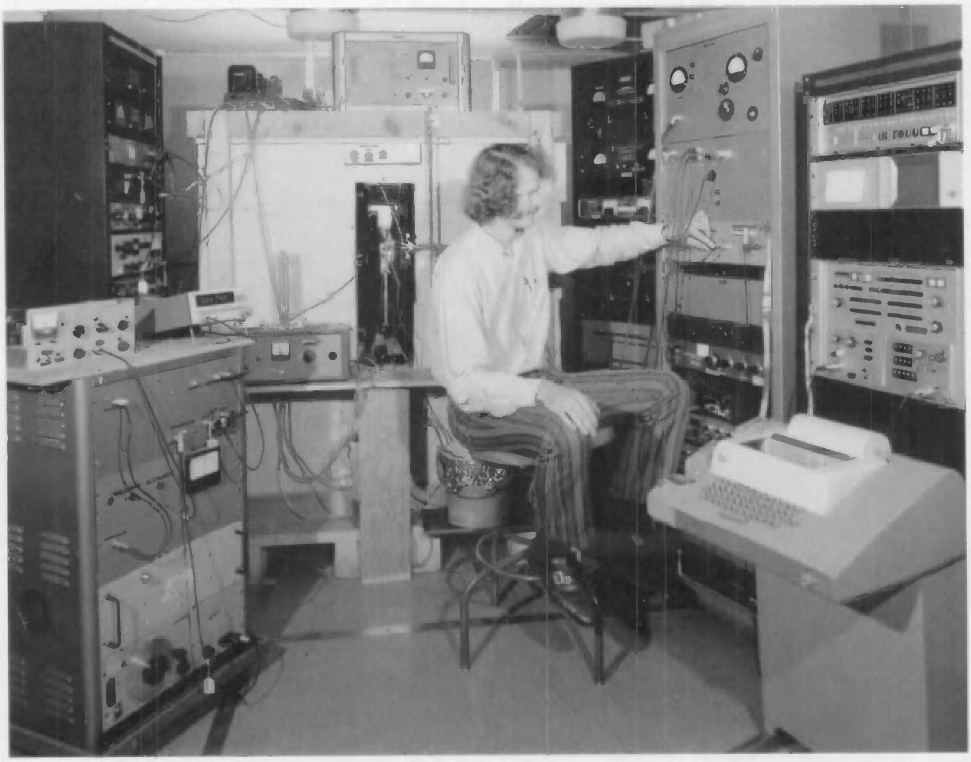
In an effort to create a reference method for estimating ^{13}C chemical shifts in solids that would still relate to earlier work with liquid tetramethylsilane, William L. Earl and David L. VanderHart performed nuclear magnetic resonance experiments on polydimethylsilane and several other materials. It was their hope to more easily characterize solid materials, including synthetic polymers.[100]

[98] I. Chabay, G. J. Rosasco, and T. Kashiwagi, "Non-intrusive technique measures concentration fluctuations in turbulent gas flow," *NBS Dimensions* **62**, pp. 22-23, April 1978. See also same authors, "Species-specific Raman spectroscopic measurements of concentration fluctuations in unsteady flow," *Journal of Chemical Physics* **70**, No. 9, 4149-4154, May 1979.

[99] P. K. Schenck and K. C. Smyth, "Opto-galvanic spectroscopy of atomic neutrals and ions in discharges," *J. Opt. Soc. Amer.* **68**, 626-627 (1978).

[100] W. L. Earl and D. L. VanderHart, "Measurement of ^{13}C chemical shifts in solids," *J. Mag. Res.* **48**, 35-54 (1982).

NBS chemist Ilan Chabay prepared for the rigors of his backpacking trips by running up and down the stairs in the 11-story Gaithersburg Administration Building with a 38 kilogram pack on his back.



David L. Vanderhart, scientist in the Bureau's Polymers Division, tuned a homemade nuclear magnetic resonance spectrometer in studies of chemical shifts in solids.

Kermit Smyth teamed with free-radical experts Sharon Lias and Pierre Ausloos from the Center for Chemical Physics to study the ion-molecule $C_3H_3^+$, which they felt played a leading role in soot formation, particularly in fuel-rich acetylene and benzene flames. They sought chemical reactivity data at thermal energies for $C_3H_3^+$ with alkenes, alkynes, and aromatic molecules. During their work, they found two isomers of $C_3H_3^+$, one linear and a second, more stable, cyclic isomer. They expected the work to be of use in the modeling of fires.[101]

The role of polycyclic aromatic hydrocarbons (PAH) in soot formation was elucidated in optical studies by J. Houston Miller, W. Gary Mallard, and Kermit Smyth. Looking for reactive intermediates, they observed PAH by optical measurements in premixed and diffusion flames, obtaining data on fluorescence in various portions of the flames.[102]

[101] K. C. Smyth, S. G. Lias, and P. Ausloos, "Ion-molecule chemistry of $C_3H_3^+$ and the implications for soot formation," *Combustion Science and Technology* **28**, 147-154 (1982).

[102] J. H. Miller, W. G. Mallard, and K. C. Smyth, "Optical studies of polycyclic aromatic hydrocarbons in pyrolysis and diffusion flame environments," pp. 905-919 in *Polynuclear aromatic hydrocarbons, 7th International Symposium on Formation, Metabolism, and Measurement,* M. W. Cooke and A. J. Dennis, editors (Battelle Press, Columbus Ohio, 1982).

Later, a test stand was built for the study of concentration behavior within turbulent flows. Nelson P. Bryner, Cecilia D. Richards, and William M. Pitts designed the stand large enough (2.4 m by 2.4 m) to examine large flows and plumes, and they utilized Rayleigh light-scattering so that concentration values could be monitored in real time in regimes of flow which heretofore were inaccessible. The stand was constructed so as to minimize optical glare and scattering by dust particles.[103]

Combustibility and Combustion Products

The question of the relative safety of hydrogen—under consideration for use as a vehicular fuel—in comparison with methane (natural gas) and gasoline was treated by Jesse Hord. Hord called attention to the relatively rapid mixing between air and hydrogen, leading quickly to an explosive atmosphere. Gasoline, by contrast, mixed relatively slowly. Each of the three substances offered fire and explosion danger, with the level of risk depending upon the circumstances of use.[104]

By the end of the 1970s, it was realized that heat-transfer fluids involving the use of polychlorinated biphenyls (PCBs) created a severe biological hazard. One of the major uses of PCBs was in electrical transformers, where the liquid was used to conduct to the outer casing any heat that was generated by electrical losses in the transformer core and in the windings. In a fire, the PCBs were likely to be spilled or ejected from the casing. Richard G. Gann published a discussion in which he noted the requirements for a replacement fluid in transformers, taking account of the high probability that either slow leakage or explosion would release the fluid. Likely candidates identified were hydrocarbons, silicone oil, and chlorinated aromatics.[105]

In 1981, Frederic B. Clarke, Irwin Benjamin, and Merritt Birky pointed out the need for laboratory toxicology measurements. These could establish the sources of toxic smoke and gases in order to provide a strong basis for regulatory decisions on construction, furnishings, and finishing materials.[106]

Toxicology was also the topic of a study by Barbara C. Levin and Emil Braun. They prepared a test stand with a combustion system that would accommodate samples of various sizes, an analytical chemistry system, and an animal exposure system. They could analyze for CO, CO_2, and O_2 in the test chamber on a real-time basis, as well as record temperature continuously. The goal of the work was to develop a new test method for toxicity.[107]

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[103] N. P. Bryner, C. D. Richards, and W. M. Pitts, "Rayleigh light scattering facility for the investigation of free jets and plumes," *Rev. Sci. Inst.* 63, No. 7, 3629-3635 (1992).

[104] J. Hord, "Is hydrogen safe?," *NBS Tech Note 690,* October 1976, 34 pp.

[105] R. G. Gann, "Development of flammability criteria for transformer dielectric fluids," *NBSIR 80-1992,* March 1980, 53 pp.

[106] F. B. Clarke, I. A. Benjamin, and M. M. Birky, "Laboratory toxicology measurements," Letter to the Editor, *Fire and Materials* 5, No. 2, 86 (1981).

[107] B. C. Levin and E. Braun, "NBS toxicity measurement method development," paper No. 11 in *3rd Expert Meeting of the Canada- Japan- USA Trilateral Cooperative Study on Fire Gas Toxicity, October 23-25, 1984,* unpublished.

The inhibition of combustion in cellulose by powders containing boron, phosphorus, sulfur or halogens as anions was tested by Robert J. McCarter. Of 185 substances tested against samples of cellulosic "terrycloth," McCarter found about half to inhibit flame formation and about one-third to inhibit both flame and smolder.[108]

In 1978, John W. Rowen reported the results of a comparative study of fire retardants in cellulose and cellular plastic. Plywood and hardboard treated by the manufacturer with fire retardant comprised the cellulose samples, and polyurethane and polystyrene, also treated by the manufacturer, made up the cellular plastic samples. The fire-retardant effectiveness was evaluated during ignition and in the rate of the heat release during the tests. Rowen found that the treated cellulose products performed better according to both criteria than did the cellular plastic.[109]

During the late 1970s, Clayton Huggett and William Parker identified a new principle, oxygen consumption, for measuring the rate of heat release, now accepted as the central property affecting fire growth. Prior measurements were based on temperature rise of the ambient air, leading to large errors because of the uneven distribution of radiant energy.[110] The ideas contained in Huggett's analysis were incorporated in the development of cone calorimeter by Babrauskas and Twilley, and later provided the basis for several international standards.

The plenary lecture at the 7th Conference on the Nonflammability of Polymers, held in Czechoslovakia during April 1983, was given by Clayton Huggett. He described some of the work of the Center for Fire Research, focusing on the flammability of both natural and synthetic polymers, and the influence of fire retardants on their performance in fires.[111]

In 1982, Alex Robertson published a description of an improved radiant heat source for use in combustion testing. A gas-fired unit, it was capable of creating temperatures as high as 935 °C over a surface 0.3 m × 0.5 m. The unit proved to be adaptable to existing test stands.[112]

Combustion products of wood under the heat fluxes found in fires interested CFR scientists Thomas J. Ohlemiller, Takashi Kashiwagi, and K. Werner. They wanted to determine the kind and level of pollutants to be expected from wood-burning stoves, which were responsible for many residential deaths. Subjecting a variety of types of wood to radiant heat in atmospheres of 0-20 % O_2 in nitrogen, they directly monitored the temperature and concentrations of H_2O, CO and CO_2, and total hydrocarbons.

[108] R. J. McCarter, "Combustion inhibition of cellulose by powders: preliminary data and hypotheses," *Fire and Materials* **5**, No. 2, pp. 66-72, June 1981.

[109] J. W. Rowen, "Role of fire retardants in time for ignition and heat release measurements," in *Proceedings of the 3rd International Conference on fire safety, January 16-20, 1978, San Francisco, CA,* unpublished.

[110] C. Huggett, "Estimation of rate of heat release by means of oxygen consumption measurements," *Fire and Materials* **4**, pp. 61-65 (1980).

[111] C. Huggett, "Fire retardant testing and fire performance," Plenary Lecture, unpublished.

[112] A. Robertson, "Development of an improved radiant heat source for fire testing," *Fire and Materials* **6**, No. 2, 68-71, 1982.

The hydrocarbons were further examined by gas chromatography and mass spectrometry, as appropriate. While they found the products to be fully as complex as they had expected, they were confident that the majority of the species could be identified and quantified.[113]

Combustibility Studies in the Space Shuttle

In a program that eventually would propel astronaut Gregory T. Linteris into space, Clayton Huggett joined a team of fire scientists to evaluate the usefulness of a space environment for the study of combustion. A. L. Berlad and C. H. Yang of the State University of New York, Frederick Kaufman of the University of Pittsburgh, George H. Markstein of the Factory Mutual Research Corporation, and Howard B. Palmer of Pennsylvania State University made up the balance of the team. After considerable thought, they came to the conclusion that the lack of gravity and the possibility of scaled-gravity experiments, the elimination of convective effects, and the possibility of homogeneous mixing of materials that could not be accomplished on earth constituted a unique experimental situation that should be pursued further, as indeed it was. Tentative assignment of experiments involved single-drop gas jets, porous solid arrays, unmixed solid-gas samples, and particle clouds.[114]

In a first for the agency, one of its own scientists performed the experiments designed for the Space Shuttle. Gregory T. Linteris, Princeton-trained mechanical/aerospace engineer, became a NIST staff scientist in 1992. He helped bring the low-gravity experiment package to completion, then applied for a spot on the shuttle microgravity mission as a payload specialist so that he could actually conduct the experiments in space. The idea suited NASA well—they wanted members of their scientific missions to be working scientists, and it was even better if the scientists had firsthand knowledge of the experiments.

Linteris and the combustion experimental package were sent into space in April 1997. After only 4 days, however, suspicious readings from one of the fuel cells of the Columbia prompted NASA to recall the flight. On July 1, 1997, a second liftoff was entirely successful. Mission STS-94, with the same crew as its predecessor, turned into a "routine"—the word seems entirely out of place for any flight into space—shuttle mission. For nearly 3 weeks, Linteris and his colleagues conducted a variety of microgravity experiments, including the combustion package prepared at NIST.[115]

[113] T. J. Ohlemiller, T. Kashiwagi, and K. Werner, "Wood gasification at fire level heat fluxes," *Combustion and Flame* **69**, No. 2, 155-170, 1987.

[114] A. L. Berlad, C. Huggett, F. Kaufman, G. H. Markstein, H. B. Palmer, and C. H. Yang, "Study of combustion experiments in space," *NASA Report CR-134744*, November 1974, unpublished.

[115] See, for example, "Second Time's the Charm," *NIST Connections*, October 1997, p. 2.

Smoke Detectors and Alarms

Interest in the topic of smoke detection in residences was spurred by fire statistics obtained for the year 1972. In that year, fire deaths per million of population in the United States reached the level of 57, nearly double the per-capita fire-death rate in Canada, the only other major industrial country experiencing a rate as high 20 deaths per million population.[116]

In 1974, Richard G. Bright urged the wider use of smoke detectors in residences, an improvement which he estimated could reduce the loss of life by 40 % to 50 %. However, he noted that the reliability of smoke detectors available at that time was uneven, and that there were no published standards for detectors. He analyzed historical data on residential fires, as well as work done at NBS and elsewhere to improve smoke detectors.[117]

Bright's paper was reprinted in 1982 in *Fire Protection Structure and Systems Design Reader,* published by Ginn Custom Publishing Company of Lexington, Massachusetts, as part of its *Open Learning Fire Service Program.*

Irwin Benjamin, then chief of the Fire Safety Engineering Division, prepared during 1980 a detailed study of the designs of fire detectors then in use in large buildings. Fire detectors, he noted, typically activated an alarm, an extinguishing system, or a specialized device. Available detectors were designed to respond to one of three conditions: when a set-point temperature was exceeded, when an aerosol exceeding a certain concentration was encountered, or when a pre-set level of radiant energy was exceeded. Temperature-activated detectors, usually employing a fusible link, a bimetallic switch, or a pneumatic switch, generally activated a sprinkler head. Aerosol detectors usually employed a photocell or an ion chamber to set off an alarm. Radiant-energy detectors made use of infrared filters, a lens, and a photocell, with the photocell signal connected to an alarm; although in some cases ultraviolet detection, at wavelengths in the range 200 nm to 300 nm, was used.[118]

A few years later, Richard W. Bukowski, at that time leader of the fire analysis group in the Center for Fire Research, described the elements of fire detection and alarm during a workshop on the technology of fire protection held in Egypt.[119] His was one of nearly a dozen CFR contributions to the workshop.

[116] "International Fire Statistics, 1972," Fire Record Department, Natl. Fire Prot. Assn., *Fire Journal* **67**, No. 6, pp. 50-51, November 1973.

[117] R. G. Bright, "Advances in residential smoke detection," *Fire Journal* **68**, No. 6, 69-77, November 1974.

[118] I. A. Benjamin, "Detector response in large buildings," pp. 1-24 in *Proc. Engineering Applications of Fire Technology Workshop, April 16-18, 1980, NBS Gaithersburg,* H. E. Nelson, editor (Boston: Society of Fire Protection Engineers, 1983).

[119] R. W. Bukowski, "Fire detection and alarm systems," *NBSIR 86-3360,* April 1986, Kurt F. J. Heinrich, Andrew Fowell, and Doris Bluebond, editors, pp. 25-38.

Smoke and Its Control

A handy tool in the study of smoke or other aerosols is a reference material that will permit the ready evaluation of the size of particulates. This tool was provided in 1985 by a team consisting of George W. Mullholland of the Center for Fire Research and Arie W. Hartman, G. G. Hembree, Egon Marx, and Thomas R. Lettieri, all from the Center for Manufacturing Engineering. They created Standard Reference Material 1690, an aqueous suspension of selected polystyrene spheres of approximately 1 μm diameter. The spheres were remarkable in that quantities were produced both in the NBS laboratories and in a space-shuttle experiment.[120] Although the spheres were produced during a 1982 space shuttle flight, SRM 1690 was offered for sale to the public after SRM 1960, described in "Measuring Tiny Space Beads" later in this chapter.

The group determined the average size of the particles in three ways; by observing the scattering of polarized laser light as it passed through the suspension; by observing the scattering of light from individual particles; and by measuring the row length generated by hexagonal close packing of the spheres in a two-dimensional array, using an optical microscope. The three methods agreed within ±0.5 %. Judging the overall uncertainty to be somewhat larger, they specified the average diameter of the spheres as (0.895 ± 0.007) μm.[121]

Even smaller aerosol particles, useful for simulating smoke conditions below the range of visible detection, could be produced with the use of low fuel flows in a laminar diffusion burner, according to more recent studies by Thomas G. Cleary, George Mulholland, Lewis K. Ives, and Robert A. Fletcher of the CFR, who collaborated on the project with J. W. Gentry of the University of Maryland. The group used acetylene, C_2H_2, to produce ultrafine aerosols, invisible to the eye but measured by transmission electron microscopy to be particles of 10 nm diameter. Particle densities of 10^6 cm^{-3} were estimated.[122]

The growth of soot in laminar flames was observed by Robert J. Santoro, Tsyh T. Yeh, John J. Horvath, and Hratch G. Semerjian, all of the Center for Chemical Engineering. The group noted that flames occurring in actual fires are not laminar, but they were convinced that soot growth in the two types of flame would be similar. In their experiment, the group prepared an ethene-air, co-annular diffusion flame and monitored the temperature and velocity of the flame as well as the size, velocity, and concentration of soot that formed at low fuel rates.[123]

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[120] G. Mulholland, G. Hembree, and A. Hartman, "Sizing of polystyrene spheres produced in microgravity," *NBSIR 84-2914,* July 1985, 26 pp.

[121] G. W. Mulholland, A. W. Hartman, G. G. Hembree, Egon Marx, and Thomas R. Lettieri, "Development of a one-micrometer-diameter particle size Standard Reference Material," *J.Res. NBS* **90**, No. 1, 3-26 (1985).

[122] T. G. Cleary, G. W. Mulholland, L. K. Ives, R. A. Fletcher and J. W. Gentry, "Ultrafine combustion aerosol generator," *Aerosol Science and Technology* **16**, 166-170 (1992).

[123] R. J. Santoro, T. T. Yeh, J. J. Horvath, and H. G. Semerjian, "Transport and growth of soot particles in laminar diffusion flames," *Combustion Science and Technology* **53**, 89-115, 1987.

Growing interest in the disposal of oil from leaking ocean-transport vessels led to experiments on the consequences of burning the spilled oil at sea. A CFR group, David D. Evans, George W. Mulholland, Daniel Gross, Howard R. Baum, and William D. Walton, collaborating with K. Saito of the University of Kentucky, created an apparatus in which they could float a pool of oil of a specified thickness on water and monitor its burning. They recorded the flame temperature, energy release rate, rate of radiation feedback, the nature of the oil residue, the pattern of the burn, and the heat balance at the burning surface. It was expected that these would become base data to be used later in modeling such oil fires.[124]

The Handbook of Fire Protection issued its first edition in 1988. It was composed of four sections: fundamentals, hazard analysis, design calculations, and risk calculations. One of the "fundamentals" contributions came from George Mulholland, who described the production and properties of smoke.[125]

The burning of oil from spills was the topic pursued by a multinational group including Bruce A. Benner, Jr., Nelson P. Bryner, Stephen A. Wise, and George Mulholland, all of CFR, and Robert C. Lao and Mervin F. Fingas of Environment Canada. Referring to the difficulties involved in disposing of oil spills in remote locations, they pressed further the question of the consequences of burning the oil *in situ.* Laboratory study and modeling convinced them that polycyclic aromatic hydrocarbons involved in such a combustion situation would be substantially reduced and that the combustion products would disperse with relatively short-lived damage to the environment.[126]

An effective, long-term investigation of the role of smoke in creating danger to humans involved in fire came from John H. Klote. Klote spent several years studying the movement and control of smoke in buildings. With J. W. Fothergill, he wrote a handbook[127] that proved very popular, serving as a text in courses on the topic and later being re-issued by the American Society for Heating, Refrigeration, and Air-Conditioning Engineering as its *Smoke Control Handbook.*

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[124] D. D. Evans, G. W. Mulholland, D. Gross, H. R. Baum, and W. D. Walton, "Burning, smoke production, and smoke dispersal from oil spill combustion," *NISTIR 89-4091*, October 1989, 57 pp.

[125] G. W. Mulholland, "Smoke production and properties," pp. 1/368-377 in *Handbook of Fire Protection Engineering,* 1st Edition, 1988, Philip. J. DiNenno, editor-in-chief, (Quincy Massachusetts: National Fire Protection Association, 1988) 700 pp.

[126] B. A. Benner, Jr., N. P. Bryner, S. A. Wise, G. W. Mulholland, R. C. Lao, and M. F. Fingas, "Polycyclic aromatic hydrocarbon emissions from the combustion of crude oil on water," *Environmental Science and Technology* **24**, No. 9, 1418-1427 (1990).

[127] J. H. Klote and J. W. Fothergill, "Design of smoke control systems for buildings," *NBS Nandbook 141,* 1983.

In a discussion prepared in 1992 for the Council on Tall Buildings and Urban Habitat, Klote wrote, "Smoke is recognized as the major killer in all fire situations." He went on to discuss details of the efforts to conquer the fatal effects of smoke in tall-building fires; we review these comments later in this section.[128]

Education

Considerable effort of the Center for Fire Research was given to activities that could be recorded under the heading of education. Lack of awareness of the dangers of fire on the part of industrial designers and workers, as well as designers, builders, and occupants of dwelling units has been cited over and over again as the single biggest contributor to fire deaths and economic loss from fire in the United States.

In this section, we cite just three examples of educational material made available by the CFR staff. John Lyons, then Director of the CFR, outlined the U.S. efforts in fire loss reduction—both contemporary and planned—as a result of the 1974 *Fire Prevention and Control Act* during an international symposium on fire safety. He noted the many organizations that participate in the fire-reduction effort in the United States: Federal, state, and local governments writing fire codes; the American Society for Testing and Materials and the National Fire Protection Association developing test methods, often with the technical assistance of the National Bureau of Standards; and the Consumer Product Safety Commission working to reduce fire danger inherent in consumer goods. Lyons called attention to the change in focus of fire science from studies devoted exclusively to fire endurance and the compartmentalization of fire to "concern for the occupants in the room of origin"—leading to more effort to understand the processes and consequences of the burning of furnishings and interior finish materials of rooms in offices, hotels, and dwelling units. He expressed the view that the new Fire Academy, given better understanding and tools, would make rapid progress in improving fire-fighting in America and in educating its citizens on fire safety.[129]

John Rockett provided a more technical form of education in a contribution to the first edition of the Society for Fire Protection Engineering Handbook. His efforts were directed to fire protection engineers; the topic was a "short course" in heat conduction in solids. Taking as his text the famous book written by Carslaw and Jaeger,[130] Rockett reviewed the mechanisms of heat transfer by radiation, conduction, and convection, applying the concepts to the special conditions and geometries of fire.[131]

[128] J. H. Klote, "Control of smoke and combustion products," pp. 17-52 in *Fire Safety in Tall Buildings*, D. Sfintesco, C. Scawthorn, and J. Zicherman, editors (New York: McGraw-Hill, 1992).

[129] J. W. Lyons, "Requirements for fire safety of combustible materials in the United States," pp. 12-19 in *International Symposium on Fire Safety of Combustible Materials, October, 1975, University of Edinburgh* (Edinburgh: University of Edinburgh, Centre for Industrial Consultancy and Liaison, 1975).

[130] H. S. Carslaw and J. C. Jaeger, "Conduction of Heat in Solids," 2nd Edition (Oxford, England: Clarendon Press, 1959).

[131] J. A. Rockett, "Conduction of heat in solids," pp. 1/49-64 in *SFPE Handbook of Fire Protection Engineering* (Quincy, Massachusetts: National Fire Protection Association, 1988).

A suggestion for a new test facility involving the generation of large-scale air motion represented a kind of educational effort, too. William M. Pitts presented such a suggestion in 1991, recalling the mass fires—fire storms and conflagrations—that accompanied the destruction of entire cities by fire, as well as countless acres of forest. Fire storms called to his mind the destructive effects of war-time bombing, resulting in tall heat columns and inwardly rushing winds that completely destroyed the targets. Wind-driven conflagrations such as those that destroyed Chelsea, Massachusetts in 1973 and routinely burned timberlands moved as the wind directed them, halting only when their fuel was gone.

Pitts assessed the need for a test facility that would help elucidate the nature and control methodology of mass fires, and he offered criteria for its design. His idea was to build a chamber similar to a wind-tunnel.[132]

Combustion of Furnishings and Room Interiors

An early discussion of combustion in rooms was given by Jin Bao Fang and Daniel Gross. They described a test facility that would allow the evaluation of the contents of a room—from wastebaskets and furniture to the ceiling, floor, and walls—from the point of view of fire science. These aspects would include the study of the items as fuel for fire, as well as the products of their combustion—smoke and toxic gases—and likely scenarios for the progress of fire in a room environment. The test chamber fire was to be ignited by a stack, or crib, of wood. With such a heat source, the scientists could examine time-to-ignition, extent of surface flame and flame penetration, and smoke and heat generation. In the work reported, Fang and Gross presented results obtained with various types of room-finish materials such as particle board, plywood, gypsum board, melamine, and vinyl and acoustic tile.[133]

The close connection they found between death from fire in space heaters and residences caused Alan Gomberg of the CFR to team with John R. Hall of the Federal Emergency Management Agency to compile statistics on the topic. Studying some 1600 fatalities occurring in 12 states over the years 1978-1979, they found that, at 53 deaths per million population, rural Americans (those in communities smaller than 2500 people) were twice as likely as their urban neighbors to die in fire. The causes that predominated for the fatal fires involved space heaters—wood stoves, kerosene heaters, and electric baseboard heaters. Improper handling of the equipment, spills during filling or cleaning, or the ignition of paper or furnishings by the devices all led to disaster.[134]

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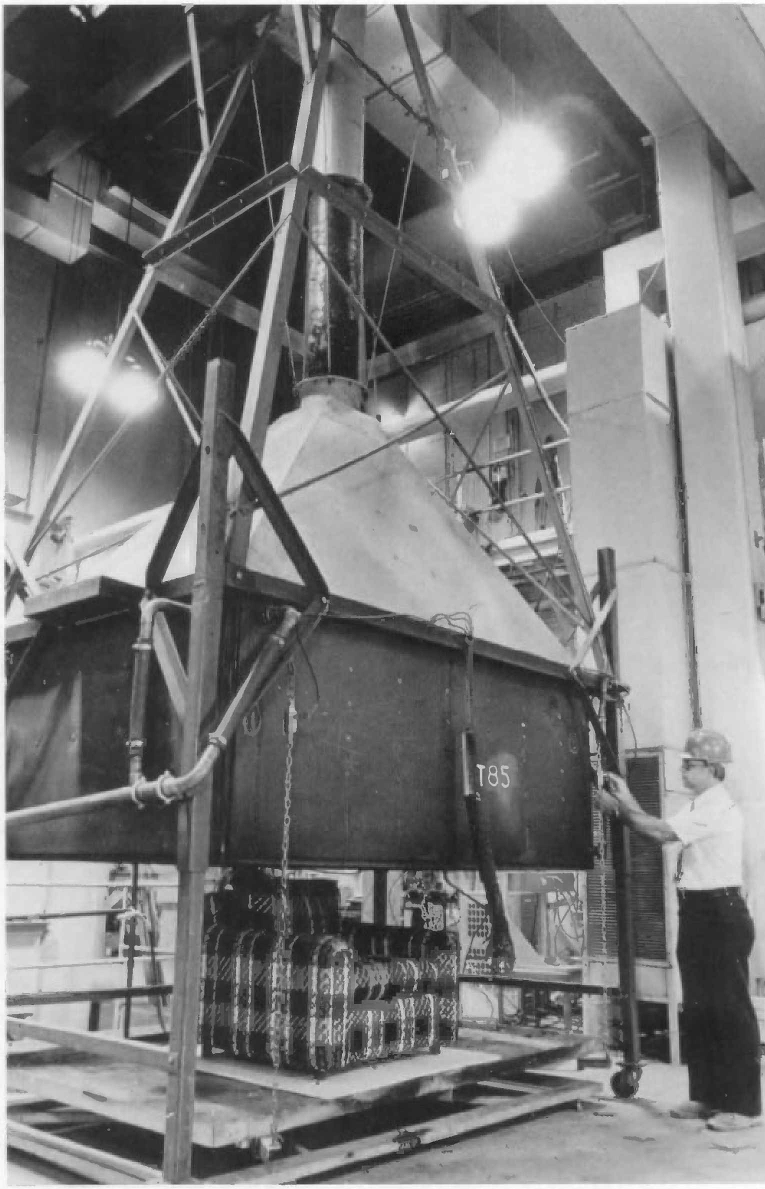
[132] W. M. Pitts, "Wind effects on fires," *Progress in Energy and Combustion Science* **17**, 83-134 (1991).

[133] J. B. Fang and D. Gross, "Contribution of interior finish materials to fire growth in a room," pp. 125-138 in *NBS Special Publication 411*, "Fire Safety Research: Proceedings of a Symposium, August 22, 1973, Gaithersburg, Maryland," Mary Jo Butler and James A. Slater, editors.

[134] A. Gomberg and J. R. Hall, "Space heater—rural death link," *Fire Service Today* **49**, No. 9, pp. 18-21, September 1982.



Bureau scientist Randall Lawson adjusted instrumentation on the furniture calorimeter, part of an NBS-developed method to measure the rate at which heat was released from burning furnishings in offices and residences.

By 1983, there existed a proposed American Society for Testing and Materials standard method for the testing of wall and ceiling materials in rooms. William J. Parker described for an international workshop NBS efforts to obtain accurate and reliable data on which the proposed standard and other advances could rest.[135]

Andrew J. Fowell addressed the methods recommended to control industrial fires, during a workshop in Cairo, Egypt in 1986. Fowell pointed out the value of using non-combustible materials in construction, of providing for the isolation of a burning area, of installing automatic sprinkler or other fire-suppression systems, and of providing for smoke control. He dwelt especially on the design aspects of sprinkler systems—water supply, valving, distribution, and release mechanisms.[136]

The results of studies of flammability of upholstered furniture and mattresses were summarized by Vytenis Babrauskas and John F. Krasny in a chapter of the *Fire Protection Handbook.* The two veterans recounted frightening fire statistics from 1982. Nearly 80,000 fires were triggered by upholstered furniture and mattresses; these translated into 1900 deaths, more than 10,000 injuries, and $500 million in economic loss. Cigarettes played the key role in 65 % of the deaths, although half of the dead were not themselves the smoker; often a forgotten cigarette would fall into a crevice in the furniture, smoldering for hours before toxic gases would snuff out the lives of sleeping residents. Babrauskas and Krasny noted that some 15 tests were available for the evaluation of fire danger from particular items of furniture, including monitoring of CO, CO_2, HCl, HCN, and NO_x. [137]

Kathy A. Notarianni of CFR described a test bay set up at the request of the National Institutes of Health to simulate a two-bed hospital room with automatic sprinklers. The setup included, besides the room itself, a simulated bathroom, corridor, HVAC system, and ports for ventilation. Both pendant and sidewall sprinkler heads could be installed. The tests involved timing the operation of various positions and types of sprinklers and smoke alarms and monitoring temperatures, smoke meters, heat flux meters, a radiometer, and concentration of gases (CO, CO_2, and O_2) throughout the bay in response to flames generated within it.[138]

[135] W. J. Parker, "NBS activities in room fire tests and heat release rates of materials," pp. 44-47 in *CIB Report Publication 81: Modeling of Pre-Flashover Fires; CIB W14 Workshop, Borös, Sweden, May 1983,* P. H. Thomas and U. Wickström, editors (Bors, Sweden: Conseil International du Batiment, Statens Provningsanstalt, 1983).

[136] A. J. Fowell, "Industrial fire suppression," pp. 63-66 in *NBSIR 86-3360,* Kurt Heinrich, Andrew Fowell, and Doris Bluebond, editors, April 1986.

[137] V. Brabauskas and J. F. Krasny, "Upholstered furniture and mattresses," pp. 12/120-128 in *Fire Protection Handbook,* 16th Edition, A. E. Cote and J. L. Linville, editors (Quincy, Massachusetts: National Fire Protection Association, 1986).

[138] K. A. Notarianni, "Five small flaming fire tests in a simulated hospital room protected by automatic fire sprinklers," *Report of Test FR 3982,* 23 pp., October 31, 1990, unpublished.

Combustion of Buildings, Aircraft, and Spacecraft

In April 1971, a disastrous fire in a nursing home killed 31 residents. The extraordinarily high loss of life was traced to unusual flammability of the floor covering used in the home's corridors. In response to this well-defined problem, L. G. Hartzell was asked by his employer, the Armstrong Cork Company, to devise a test method for flooring materials. He worked on two aspects of flammability: ease of ignition of the flooring material, to establish its danger as a source of fire; and flammability rate, to establish its contribution to prolonging and extending a fire. As his work progressed, he came to NBS as a Research Associate to help adapt the method for possible use by the ASTM.[139] Sanford Davis of the CFR and his colleague C. Howard Adams, a Bureau Research Associate from the Society of the Plastics Industry, later summarized the results of the test-method development, which eventually incorporated a device that would subject a 20 cm × 100 cm specimen to radiant or burner heating while allowing measurements of air supply and temperatures, both by radiometric means and by thermocouple thermometers.[140]

In 1972, the National Transportation Safety Board requested that NBS help in the investigation of an explosion on March 24, 1972, that killed several residents of Canterbury Woods, Virginia, and destroyed or damaged three homes when a backhoe ruptured a natural gas pipeline in the vicinity. Robert W. Beausoliel, Clinton W. Phillips, and Jack E. Snell responded to the request and, using tracer gas, were able to determine the pathways by which the natural gas penetrated the homes in order to build up explosive gas concentrations.[141]

Dozens of tall buildings suffered disastrous fires throughout the world in this century, leading to considerable effort on the process by which the smoke and flame could be restricted to a small area of the building. Francis C. Fung described experiments conducted in the 36-story Seattle Federal Building and in the 42-story Chicago Federal Building, using SF_6 tracer gas to mark the path of simulated smoke through the rooms and corridors as emergency smoke-control air-handling systems attempted to isolate the "burn room." The burn room was equipped with a heavy-duty blower to propel the heated air-plus-tracer-gas mixture into the corridor. The experiment showed that the emergency systems succeeded by exhausting the air from the fire zone, replacing it with pressurized air from both above and below.[142]

A deadly fire broke out in the 26-story MGM Grand Hotel, crowded with visitors to Las Vegas, Nevada, on November 21, 1980. The blaze left 85 persons dead. In an

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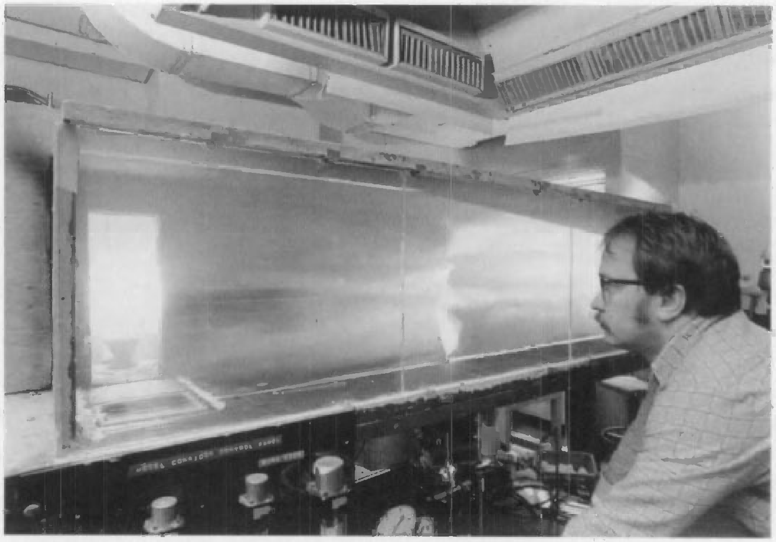
[139] L. G. Hartzell, "Development of a radiant panel test for flooring materials," *NBS Interagency Report NBSIR 74-495*, May 1974, 49 pp.

[140] C. Howard Adams and Sanford Davis, "Development of the flooring radiant panel test as a standards test method," *NBSIR 79-1954*, March 1980.

[141] R. W. Beausoliel, C. W. Phillips, and J. E. Snell, "Field investigation of natural gas pipeline accident: Canterbury Woods, Annandale, Virginia," *Fire Journal* **68**, No. 3, 77-84, May 1974.

[142] F. C. W. Fung, "Smoke control by systematic pressurization," *Fire Technology* **11**, No. 4, 261-269 (1975).



As part of a general NBS study to develop effective means of predicting fire behavior in buildings, William J. Rinkinen observed streak lines from titanium dioxide smoke injected into a room-corridor fire-simulation model. The apparatus contained instruments to record pressure, temperature, and gas flow.

effort to establish the cause of death, Merritt Birky, Maya Paabo, and NBS Guest worker Dolores Malek teamed with D. Mayne, Coroner of Clark County, Nevada, to study tissue samples from the victims. Tests indicated that the great majority of the victims—75—died from inhalation of smoke and carbon monoxide. Another eight died from smoke inhalation, burns, or a combination of these causes. One died of a blow to the head during the fire, and one suffered a fatal heart attack. The results showed again the potent danger of smoke and toxic gases in fires.[143]

Another casino fire, this time in the Dupont Plaza Hotel and Casino in San Juan, Puerto Rico, on New Year's Eve, 1986, took 97 lives. All but a few were so badly burned as to be unidentifiable. The Bureau staff once again was involved in the analysis of the fire.[144] Harold E. Nelson prepared an engineering analysis of the fire. The fire apparently ignited in a cardboard box containing upholstered furniture that was stored on the first floor of the 20-story hotel. Also on the first floor were a ballroom complex, a foyer, a lobby, and connecting corridors. Nelson, part of a team that included representatives of the Bureau of Alcohol, Tobacco, and Firearms; the U.S. Fire Administration; the U.S. Fire Academy; and the National Fire Protection Association, used eyewitness accounts where available to verify the actual progress of the fire in

[143] M. M. Birky, D. Malek, D. Mayne, and M. Paabo, "Study of biological samples obtained from victims of MGM Grand Hotel fire," *J. Analytical Toxicity* 7, 265-271 (1983).

[144] H. E. Nelson, "Engineering analysis of the early stages of fire development: the fire at the Dupont Plaza Hotel and Casino, December 31, 1986," *NBSIR 87-3560*, 113 pp., April 1987.

comparison with a model prepared using available data on the structure and its furnishings. He found that 10 minutes after ignition, the fire had spread through the ballroom and had created sufficient momentum that flashover occurred, bursting windows and sending fatal concentrations of smoke and toxic gases throughout the ballroom and foyer areas. Within another 3 minutes, the casino area was in flames. Nelson was able to provide other fire scientists with detailed predictions—estimated to be accurate within about 25 %—of many features of the fire, including mass burn rates, rates of heat release, smoke temperatures, velocities of the fire and smoke fronts, and response of fire-suppression sprinklers.

Barbara Levin, an expert in toxicology, participated with Pio R. Rechani, Fransisco Landron, Jose R. Rodriguez, Lucy Droz, Flor M. deCabrera, and Sidney Kaye of the Puerto Rico Institute of Forensic Science (IFS), with Joshua L. Gurman of the American Iron and Steel Institute, and with Helene M. Clark and Margaret F. Yoklavich of the University of Pittsburgh, in a study of tissue and blood samples from the fire victims.[145] Levin and her group screened the samples for carboxyhemoglobin and cyanide at the IFS in Puerto Rico, moving the positive samples to NBS for quantitative testing. They found that those persons who were badly burned in the fire—some 78 of the victims—were not killed by toxic gas, but rather by heat alone, so intense was the fire.

Jack Snell was asked by the Subcommittee on Science, Research, and Technology of the House Committee on Science, Space, and Technology to testify on NBS work on the Dupont Plaza fire. Later, with the assistance of Harold Nelson, Snell published the substance of the testimony as part of the *4th International Fire Conference.* Snell recounted that Nelson and James Quintiere of the CFR had been able to provide on-the-spot-analysis of the fire to assist local investigators, using portable computers programmed with CFR fire-modeling information. He noted that arson was suspected in the origin of the fire, but that the proximate cause of death for most of the dozens of victims lay with the design and construction of the hotel, with its fire-protection systems, and with the level of emergency training given the hotel staff.

Snell stated that several minor changes in the situation would have saved both life and property:

- Had an operating sprinkler head been located within 10 feet of the point of origin, the fire would have been extinguished within 3 minutes, well short of causing fatalities.

- Had an operating smoke detector been located in the room of origination, an alarm would have sounded within 15 seconds of ignition.

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[145] B. C. Levin, P. R. Rechani, F. Landron, J. R. Rodriguez, L. Droz, F. M. deCabrera, S. Kaye, J. L. Gurman, H. M. Clark, and M. F. Yoklavich, "Analysis of carboxyhemoglobin and cyanide in blood from victims of the Dupont Plaza Hotel fire in Puerto Rico," *J. Forensic Sciences* **35**, No. 1, 151-168 (1990).

- Had an existing standard code for fire resistance of interior walls (providing a 1 hour delay in fire penetration) been applied to the hotel construction, the foyer and casino fatalities would likely not have occurred.[146]

The frightening predicaments encountered by residents of high-rise retirement homes were illustrated by a deadly fire in Johnson City, Tennessee, that occurred the day before Christmas, 1989, in the John Sevier Retirement Center. The 11-story structure was flanked by a single-story wing on one side and by a three-story wing on the other. Fire broke out in the one-story wing, igniting combustible ceiling materials. Although the local fire department responded promptly (estimated at 4 minutes after the alarm), hot, toxic gases killed 16 residents, almost all on upper floors of the central building. Kenneth D. Steckler, James G. Quintiere, and John H. Klote analyzed the fire debris and noted two key features that doomed the victims: firstly, the hidden combustible ceiling materials—mostly wood-fiber tiles—provided so much fuel that when flashover occurred, oxygen levels were severely depleted, leading to fatal concentrations of carbon monoxide; secondly, the elevator shafts provided a natural chimney for the hot, toxic gases to reach the upper floors, trapping the occupants, many of whom could not use the stairs because of their physical disabilities.[147]

In the Introduction to a publication mentioned earlier,[148] Joseph Zicherman catalogued some 37 major fires occurring in tall buildings. The fires in the Las Vegas MGM Grand Hotel, the San Juan Dupont Plaza, and the Johnson City Sevier Retirement Center, disastrous as they were in terms of loss of life and property, served to illustrate the central fact of tall-building fires: smoke and toxic gas was the killing agent most of the time. John Klote, in a 35-page discussion, described progress in the treatment of smoke in high-rise buildings. He noted that pressurization of stairwells was introduced in the 1960s, requiring zoned HVAC systems. The next step was the "pressure sandwich"; pressurization from above a burning floor and below was coupled with exhaust from the burn area to restrict smoke and gases to the burning floor. Specialized air-handling equipment was needed for emergency use, along with smoke barriers, vents and shafts.

Relatively little was written about the psychology of arson. According to Bernard M. Levin, this paucity resulted from the fact that only the "least successful" arsonists—those who were caught and those who confessed—were available for study. Writing in the journal *Fire and Arson Investigator*, Levin identified three major

[146] J. E. Snell and H. E. Nelson, "Summary of the National Bureau of Standards' analysis of the Dupont Plaza Hotel Fire," pp. 98-105 in *4th International Fire conference, March 22-24, 1988, Cambridge, England,* Interflam '88, Vol. 13, "Fire and Materials," S. P. Rogers and R. M. Quarterman, editors (New York: John Wiley and Sons, 1988).

[147] K. D. Steckler, J. G. Quintiere, and J. H. Klote, "Johnson City fire: Key factors," NIST Letter Report, 1990, unpublished.

[148] J. H. Klote, "Control of smoke and combustion products," pp. 17-52 in *Fire Safety in Tall Buildings,* D. Sfintesco, C. Scawthorn, and J. Zicherman, editors (New York: McGraw-Hill, 1992).

motivations for arson: for-profit, typified by insurance fraud and arson to cover criminal evidence; revenge or pyromania, generally involving only one person; and vandalism, riot, or political motives, generally involving a group of people.[149]

Early in a study of residential fire (although residential fires constituted only 28 % of reported fires, they accounted for 78 % of the deaths and 58 % of the economic dollar losses at that time), room-scale floor-fire testing was described by Jin Bao Fang. Tests of seven weighted structures, four of unprotected wood and three of light steel, resulted in average time-to-failure of 10-12 minutes and less than 4 minutes, respectively. The steel floor, though not itself combustible, buckled long before the wood lost its strength. Protecting the steel members by a covering of gypsum board lengthened its service life to about 16 minutes.[150]

A survey of the types and amounts of "fuel" available in residential fires was conducted by Lionel A. Issen. He reported data for 359 residences in the Washington, DC area, mostly single-family detached houses but including single-family attached and mobile homes. The logic used in cataloging the value of household furnishings as "fuel" involved the use of an average figure for their energy of combustion—8000 Btu/lb. This simplification permitted the survey to estimate the total energy available in terms of the total weight of the furnishings in any given room.[151]

A major source of fire in residences, particularly those in which wood-burning stoves contributed to the heating, was chimneys. Accordingly, the CFR carried out experiments on behalf of the Consumer Product Safety Commission and the U.S. Department of Energy in which several chimneys were purchased or constructed, then loaded with condensibles from fires of various kinds of wood. Richard D. Peacock, who reported the results, noted that the vernacular name for the condensibles was "creosote," which often was taken to include "everything but the birds' nests." The test burns were performed on the chimneys with no external restrictions on airflow; the results were given in terms of maximum chimney temperature and fire duration. The maximum temperatures generally reached 800 °C (1500 °F). Peacock gave minimum specifications for safe use of masonry chimneys; a fire-clay liner of at least 1.6 cm thickness, masonry of at least 10 cm thickness, and an air gap separating the two.[152]

A user-interactive computer program for evaluating heat-detection systems installed in buildings was presented in a massive (557-page) tome both in the *BASIC* and the *FORTRAN* languages. The compilation was prepared by David W. Stroup, David D. Evans, and Phyllis M. Martin.[153] The report included a number of examples treated with the use of the program.

[149] B. M. Levin, "Psychological characteristics of firesetters," *Fire and Arson Investigator* 27, No. 4, 12-22 (1977).

[150] J. B. Fang, "Fire performance of selected residential floor materials," *NBSIR 80-2134*, December 1980, 79 pp.

[151] L. A. Issen, "Single-family residential fire and live loads survey," *NBSIR 80-2155*, December 1980, 176 pp.

[152] R. D. Peacock, "Chimney fires: Intensity and duration," *Fire Technology* 22, No. 3, 234-252 (1986).

[153] D. W. Stroup, D. D. Evans, and P. M. Martin, "Evaluating thermal fire detection systems (SI Units). Final Report," *NBS Special Publication 713*, April 1986, 557 pp.

In response to a request from the National Institutes of Health for data on which to base the design of new chemical laboratories, William D. Walton of CFR prepared a test facility to simulate the response of various types of sprinkler systems to bench-top fires. Acetone, an extremely flammable solvent, was selected as the test fuel; measurements were made of the flame temperature and the concentrations of O_2, CO, and CO_2 as standard sprinklers, quick-acting sprinklers, or no sprinklers at all were used to suppress the fire. Both types of sprinkler were effective in dousing the flames, but without sprinkler protection, the fires were judged to be lethal to bystanders.[154]

On October 17, 1989, a strong earthquake shook northern California; it was estimated to have been the most severe disturbance along the San Andreas fault since 1906. The epicenter of what came to be called the *Loma Prieta Earthquake* was placed at a spot 16 km northeast of the city of Santa Cruz and some 18 km deep in the earth. Damage in the Bay Area was extensive—62 dead, more than 3500 injured, 12,000 people displaced from their homes, some $6 billion in property loss. A 50-foot span of the San Francisco-Oakland Bay bridge collapsed, as did elevated sections of Interstate 880 in Oakland. A six-member team from NIST, led by Hai S. Lew, joined representatives of the Federal Highway Administration, the Department of Housing and Urban Development, and the U.S. Geological Survey to assess the damage.

Harold E. Nelson of CFR examined the state of the Bay Area fire protection systems after the shock. He found that most private fire-protection facilities survived the quake in serviceable condition, but that the public fire-protection systems suffered extensive interruption. Had the quake been accompanied by widespread fire in San Francisco, he said, the public fire response would have been hamstrung by inoperative equipment. In Nelson's opinion, substantial fire losses were avoided only because electric utilities were shut down according to emergency procedures and because safeguards had become so common on the pilot lights of gas appliances. Good fortune also played a role—the weather was warm, so that most home-heating furnaces were turned off, and there was little or no wind on that day.[155]

At a U.S. Navy facility, equipment used to train fire-fighters was found to malfunction in high winds. Designed to simulate actual pool fires involving jet fuel, the trainer propane-burner assembly located beneath the apparatus would become engulfed in flame under certain conditions on very windy days. Glenn P. Forney and William D. Davis modeled the trainer geometry in an effort to quickly determine how best to counter this malfunction. Their model indicated that the blow-down could be corrected by the installation of a wind-deflecting fence plus pressurization of the burner area. The solution proved satisfactory, quickly restoring full use of the trainer.[156]

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[154] W. D. Walton, "Quick response sprinklers in chemical laboratories: fire test results," *NISTIR 89-4200*, November 1989, 49 pp.

[155] H. E. Nelson, "Performance of fire protection systems," pp. 6/1-3 in *NIST Special Publication 778*, "Performance of Structures During the Loma Prieta Earthquake of October 17, 1989," H. S. Lew, editor, 201 pp., January 1990. The Loma Prieta earthquake is discussed from a structures perspective in Ch. 6.

[156] G. P. Forney and W. D. Davis, "Analyzing strategies for eliminating flame blow-down occurring in the Navy's 19F4 fire fighting trainer," *NISTIR 4825*, 56 pp., May 1992.

Fire aboard spacecraft remained a terrifying prospect throughout the decades of the 1970s and 1980s. The Center for Fire Research was involved in both experimentation and modeling in order to minimize the danger from fire. Takashi Kashiwagi participated in a workshop on combustion in microgravity which was sponsored by the National Aeronautics and Space Administration during January of 1989.

Kashiwagi noted the differences between ordinary building fires on earth and fires in spacecraft:

- Most obvious, the crew of the spacecraft could not evacuate a burning compartment at a moment's notice.
- Detection of space combustion was made more difficult by the lack of upward, buoyancy-induced convection.
- Quick detection and nearly no false alarms were vitally important.
- Equally crucial was rapid suppression of any actual blaze, perhaps with a nitrogen-pressurized foam.
- Emergency extinguishment was a necessary option, perhaps by venting ambient oxygen in the cabin to space.

Kashiwagi also suggested a number of areas in which research could usefully be undertaken: flow calculations in the capsule; development of a fire-decision algorithm; development of specialized detectors for space use; data on the burning of materials in microgravity; and development of specialized fire extinguishers for use in space.[157]

Later, Kashiwagi teamed with Richard L. Smith to further explore the idea of an "expert system" for space use which would combine problem-solving programs with a knowledge base and a reasoning mechanism. Such a system, according to Kashiwagi and Smith, could provide solutions to the problems of quick fire detection and suppression and drastic measures for coping with out-of-control fires.[158]

The deliberate setting of oil-well fires in Kuwait during the invasion of Kuwait by Iraq consumed an enormous amount of crude oil in the Al Mawqa-Al Ahmadi fields. The Kuwait Oil Company estimated a peak loss of 6 million barrels of oil per day during the height of the action. Daniel Madrzykowski and David D. Evans performed thermal radiation measurements in an effort to test the feasibility of determining the heat-release rates of individual well fires by a combination of radiation and flame-height data. Data were obtained on a dozen fires burning at estimated rates of 1500-30,000 barrels per day. Extrapolating these measurements to the total of 651 wells yielded a figure of 7.4 million barrels per day, in good agreement with the Kuwait Oil Company estimate.[159]

[157] T. Kashiwagi, "Suggested approach for fire safety of the space station," pp. 1-5 in *NASA International Workshop. on Microgravity Combustion,* January 25-26, 1989, Cleveland Ohio, unpublished.

[158] R. L. Smith and T. Kashiwagi, "Expert systems applied to spacecraft fire safety," *Journal of Applied Fire Science* **1**, No. 2, pp. 102-113, 1990.

[159] D. Madrzykowski D. D. Evans, and Gerald A. Hayes, "Large fires: Kuwait," *Proceedings of the 12th panel meeting of the United States-Japan Government Cooperative Program on Natural Resources, October 27- November 2, 1992,* unpublished.

Fire Data Compilations and Calculations

Throughout its existence, the Center for Fire Research actively engaged in compiling fire data and recording the results of fire calculations, often obtained by modeling techniques. These contributions sometimes involved basic heat, heat-transfer and thermodynamic data, the modeling of particular types and properties of fire, or the effects of fire on people.

A key ingredient to the usefulness of CFR work was the ready availability of reports, books, and compilations. The Fire Research Information Service, headed by Nora H. Jason, offered annual compilations of references to research in fire.[160]

Data on Fire-related Properties of Materials

As examples of the compilation of information on the properties of materials as they relate to fire, we cite the calculation of emissivity and absorptivity of combustion products in building corridors, by K. Bromberg and James G. Quintiere, and a comparison of the relative influence on flame extinction of induced temperature decrease and heats of combustion of fuels, by Andrej Macek.[161]

Fire Modeling

Daniel Gross and Alexander Robertson produced theoretical models of fire as early as the mid-1960s, while John Rockett was beginning his own work in modeling. During the 1970s, the focus of modeling changed from predictions relating to the burn duration for entire buildings to more detailed efforts to model the early stages of residential fires. So-called "zone" models treated individual rooms or floors of buildings. Jeffrey P. Cohn described the Work of Gross, Robinson, and Rockett, and also more recent work by Walter Jones on the modeling of smoke movement.[162]

One of Director Ambler's efforts to stimulate new scientific work at NBS was to set aside a small amount of money to fund what were called *Competence Proposals*. One of the first of these went to Howard Baum of the Center for Fire Research and Ronald Rehm of the Center for Applied Mathematics, who collaborated on a study that eventually formed the basis for all of the computational fluid dynamics modeling of

[160] See, for example, N. H. Jason, "Fire Research Publications, 1980," *NBSIR 81-2272,* 16 pp., April 1982. These bibliographies typically provided access to journal articles, conference proceedings, NBS publications—interagency reports, technical notes, special publications, and handbooks—contract and grant reports, and an author index.

[161] K. Bromberg and J. G. Quintiere, "Radiative heat transfer from products of combustion in building corridor fires," *NBSIR 74-596,* 26 pp., February 1975. See also Andrej Macek, "Flammability limits: Thermodynamics and kinetics," *NBSIR 76-1076,* 22 pp., May 1976.

[162] J. P. Cohn, "Firefighting in the computer age using math and computer models to study fire." *NBS Dimensions* **65**, No. 6, pp. 2-5, August 1981.

fire and combustion over a 20-year span.[163] Their work—cited by many researchers both within and outside NBS—made possible the development of simulations that could quickly be prepared for calculation on desktop computers.

There were many other contributions to the science of modeling fire. For example, Howard Baum also calculated how a point source of heat could generate laminar airflow in the surrounding volume.[164] In another example, David Evans generated a model for the temperature rise from resistive heating in electrical cables.[165] And in 1980 Robert Levine developed a model to predict the growth of fire in compartments.[166]

Other contributors to fire modeling included Fred I. Stahl, Leonard Y. Cooper, Robert E. Chapman, James G. Quintiere, Rosalie T. Ruegg, Ronald G. Rehm, Daniel W. Lozier, Daniel M. Corley, Vytenis Babrauskas, Richard W. Bukowski, Henri E. Mitler, Marc R. Nyden, Glenn Forney, and James E. Brown.

Fire Statistics

Edward K. Budnick collected statistics on U.S. fire deaths in relation to the installation of smoke detectors and sprinklers. He found that, per capita, more people died in residential fires than in other types of buildings. However, the use of smoke detectors and sprinklers reduced the probability of death by as much as 75 %.[167]

Statistics on electrical fires were collected by John R. Hall, Richard W. Bukowski, and Alan Gomberg. They surveyed some 105 fire reports in ten U.S. cities—Akron, Grand Rapids, Long Beach, Oakland, Portland, Sacramento, San Diego, San Francisco, San Jose, and Toledo. They catalogued the locations of the fires and the extent of code violations (as many as 60 %) associated with them.[168]

Books and Conference Proceedings

In fire science, it was important to communicate information on advances in fighting fire—lives depended upon it. For many responsible parties, conference attendance provided a vital boost to fire-fighting progress; information could be obtained directly from the primary investigators and they could be quizzed about the best means to apply new results.

[163] R. Rehm and H. Baum, "The equations of motion for thermally driven, buoyant flows," *J. Res. NBS* **83**, pp. 297-308 (1978).

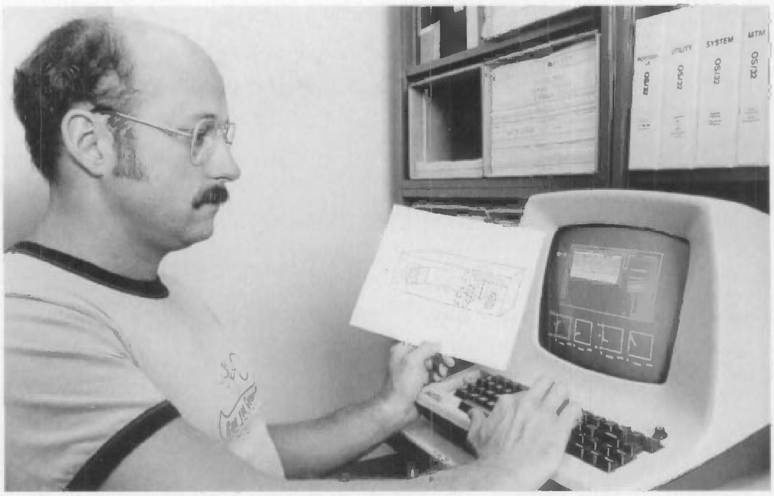
[164] H. R. Baum, "Laminar flow induced by a point source of heat," *J. Res. NBS* **81B**, No. 1, pp. 45-60, 1977.

[165] D. D. Evans, "Modeling for determination of temperatures of electrical cables within thermally insulated walls," *NBSIR 80-2129,* 28 pp., October 1980.

[166] R. S. Levine, "Mathematical modeling of fires," *NBSIR 80-2107,* 44 pp., September 1980.

[167] E. K. Budnick, "Estimating effectiveness of state-of-the-art detectors and automatics sprinklers on life safety in residential occupancies," *Fire Technology* **20**, No. 3, pp. 5-22, August 1984.

[168] J. R. Hall, R. W. Bukowski, and A. Gomberg, "Analysis of electrical fire investigations in ten cities," *NBSIR 83-2803,* 35 pp., December 1983.



Walter W. Jones of the NBS Center for Fire Research compared the results of a computer model's calculations with a schematic of the actual experiment that the model simulated.

Bureau fire staffers participated frequently in conferences and contributed to books and handbooks on the subject of fire research. A partial listing of conferences routinely attended by CFR personnel and handbooks and texts written by them follows. The organizations sponsoring the production of the handbooks and textbooks are included in parentheses:

Conferences Attended

- International Symposium on Combustion.
- National Heat Transfer Conference.
- Heat Release and Fire Hazards.
- International Symposium on Fire Safety Science.
- International Conference on Fire and Materials.
- Information Council on Fabric Flammability.
- International Conference on Flammability.

Handbooks

- Handbook of Fire Protection Engineering (Society for Fire Protection Engineering).
- Fire Protection Handbook (National Fire Protection Association).
- Fire Investigation Handbook (NBS Handbook 134).

Textbooks

- Heat Release in Fires (Elsevier Applied Science).
- Fire and Flammability of Furnishings and Contents of Buildings (ASTM STP 1233).
- Fire Safety: Science and Engineering (ASTM STP 882).
- Mathematical Modeling of Fires (ASTM STP 983).
- Fire Standards and Safety (ASTM STP 614).
- Performance of Protective Clothing (ASTM STP 900).

Standards and Calibration

Work in the areas of standards and calibration occupied many researchers and other staff members of NBS during this period, as the following selections demonstrate.

Proton Gyromagnetic Ratio

After several years of painstaking research, Edwin R. Williams and P. Thomas Olsen completed a redetermination of the gyromagnetic ratio of the proton in 1979. In turn, their measurement allowed them to set a new value for the fine-structure constant, a central component of one of the most fundamental and accurate theories of physics—quantum electrodynamics (QED).[169]

Quantum electrodynamics was used in discussions of all the physical phenomena that did not directly involve nuclear forces, gravitation, or weak interactions. Electrical and magnetic interactions of subatomic particles, for example, could be accounted for by the use of QED. The fine-structure constant, designated by the Greek letter α, entered QED as one of the physical quantities that appeared in many of its equations; therefore better accuracy for the fine-structure constant could lead immediately to more penetrating tests of the reliability of QED as a physical theory.

The two Bureau physicists set up their experiment around a small spherical sample of water—a substance dense in protons—positioned within a solenoid wound, with great precision, of copper wire. The solenoid was powered by a direct current that was carefully measured in terms of the U.S. standard ampere. Detection of the precession frequency of the protons by nuclear magnetic resonance, a determination involving highly accurate frequency measurements, was possible with an uncertainty considerably less than 1 ppm. Part-per-million calculation of the magnetic flux density generated by the solenoid, however, presented a serious stumbling block to the success of the experiment. this was so because of the uncertainty of the solenoid dimensions and the

[169] E. R. Williams and P. T. Olsen, "New measurement of the proton gyromagnetic ratio and a derived value of the fine- structure constant accurate to a part in 10^7," *Phys. Rev. Lett.* **42**, No. 24, 1575-1579 (1979).

uncertainty of the location of the current elements within the copper wire. Williams and Olsen finally hit upon use of sensitive probe coils and a laser interferometer to minimize uncertainty in the magnetic flux density determination.[170]

As a result of their experiment, Williams and Olsen evaluated α to one part in 10^7, reducing its uncertainty by a factor of ten.[171] The Williams-Olsen experiment also had the virtue that its determination of the fine-structure constant was independent of QED theory; thus their value could be used to test the theory itself.

Study of the gyromagnetic ratio of the proton had a long history at NBS even before the work of Williams and Olsen. Raymond L. Driscoll and Peter L. Bender used laboratory space borrowed in 1958 from the U.S. Coast and Geodetic Survey to provide the first high-accuracy measurement (about ten parts per million) of the quantity. Their work led to improved electrical standards, allowing a continuing check on the stability of the NBS chemical cells used to define the volt until about 1970.

By 1988, the Williams-Olsen experiment had been refined, its uncertainty being reduced by about a factor of two. The new research was performed in collaboration with Marvin E. Cage, Ronald F. Dziuba, Randolph E. Elmquist, Bruce F. Field, George R. Jones, Willliam D. Phillips, John Q. Shields, Richard L. Steiner, and Barry N. Taylor. The group's experiments provided information about the time-dependence of the NBS ohm and the NBS volt representation, as well as the low-field proton gyromagnetic ratio.[172]

In 1989, Cage, Dziuba, Olsen, Shields, Taylor, and Williams received the Department of Commerce Gold Medal Award for their group effort on behalf of electrical standards. The justification for the award read, in part:

> This group has made contributions without which the 1990 international adjustment of electrical units could not take place. They performed four key experiments linking the (International System of Units) definitions of the electrical units to NIST national standards at unprecedented levels of accuracy.

[170] A discussion of the experiment in down-to-earth language was given by Michael Baum, "The precisely precessing proton," *Dimensions/NBS* **63**, No. 11, November 1979, pp. 10-17.

[171] The reported values were: for the gyromagnetic ratio of the proton, measured at low magnetic field in water, $2.675\ 132\ 29 \times 10^8\ s^{-1}\ T_{NBS}^{-1}$, within 0.21 ppm; for the inverse of the fine- structure constant, 137.035 963, within 0.11 ppm.

[172] M. E. Cage, R. F. Dziuba, R. E. Elmquist, B. F. Field, G. R. Jones, P. T. Olsen, Willliam D. Phillips, J. Q. Shields, R. L. Steiner, Barry N. Taylor, and E. R. Williams, "NBS determination of the fine-structure constant, and of the quantized Hall resistance and Josephson frequency-to-voltage quotient in SI units," *IEEE Transactions on Instrumentation and Measurements* **IM- 38**, No. 2, pp. 284-289 (1989). See also E. R. Williams, G. R. Jones, S. Ye, R. Liu, H. Sasaki, P. T. Olsen, W. D. Phillips, and H. P. Layer, "Low field determination of the proton gyromagnetic ratio in water," *IEEE Transactions on Instrumentation and Measurement* **IM-38**, No. 2, pp. 233-237 (1989).

High-Precision Measurement and Test Equipment Program

On June 13, 1977, the U.S. General Accounting Office (GAO), "charged with examining all matters relating to the receipt and disbursement of public funds,"[173] recommended that the Office of Management and Budget (OMB) create a centralized scheme for program direction and coordination of instrument calibration systems used by civilian agencies. In turn, the OMB quickly asked Commerce Secretary Juanita Kreps to have NBS take the lead for coordinating improvements in the management and use of "high-precision" measurement and test equipment (PMTE) among civilian agencies.

The Federal expenditure in the category represented by PMTE exceeded $2.7 billion per year, including more than $250 million in direct calibration expenses. The GAO had recently commended the Department of Defense for its sophisticated system that coordinated PMTE use within the military, although the GAO was less happy with the duplication of effort that it found there.[174] Coordination among civilian agencies was poor, according to the GAO; considerable savings appeared possible if the civilian system were to be improved.[175]

Responding to the Secretary's request, Director Ambler assigned the Office of Measurement Services (OMS) to prepare a plan to take the lead role as requested, to help civilian agencies improve their PMTE programs, and to report to the Office of Management and Budget any needed actions. Brian C. Belanger, then head of the OMS, directed the planning effort, which was approved by OMB in mid-1978.

The new PMTE Project was managed by Jack Vogt. His staff included Kathryn Leedy, Kenneth Edinger, Brenda Schriver, and Joanne Mobley. The array of Federal agencies using highly precise measurement and test equipment was impressive. Besides the Department of Defense, the list included most of the technical agencies—the departments of transportation, energy, health and human services, agriculture, and labor, as well as subsidiary or independent organizations such as National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, the U.S. Postal Service, the Federal Communications Commission, the General Services Administration, the Tennessee Valley Administration, the Consumer Product Safety Commission, and the Nuclear Regulatory Commission. Coordinating PMTE activities among such a large group would be no easy task.

One of the first activities undertaken by the PMTE project staff was the preparation of a *Catalog of Federal Metrology and Calibration Capabilities,* intended to promote cooperation among federal agencies. It contained a listing of laboratories using highly

[173] *The United States Government Manual 1997-98,* (Washington, DC: Office of the Federal Register, National Archives and Records Administration, 1997) p. 46.

[174] GAO Report #LCD-427 *A Centralized Manager is Needed to Coordinate the Military Diagnostic and Calibration Program.*

[175] GAO Report #LCD-426 *Centralized Direction Needed for Calibration Program.*

precise measurements and their equipment, along with the name of a contact person in each laboratory. The entries were coded to indicate 17 different types of measurements used in some 270 laboratories.[176]

A newsletter, *PMTE Update,* was issued twice a year to improve communications among the user laboratories on topics such as new developments in precise equipment, publications and meetings, management strategies, and current issues in testing and calibration. Two thousand copies of the newsletter were circulated in 1981.

The NBS project funded cost-effectiveness studies performed by the Raytheon Service Company. These covered calibrations, measurement assurance programs, and government-wide calibration-interval practices.

Issues such as the use of Automatic Test Equipment, traceability of measurements to national standards, focal points for improved training and recruitment, standardization of procedures for calibration, and a handbook of standard terms and definitions were treated during the comparatively short (3 years) lifetime of the project.

Pressed by a personnel shortage during 1981, the Bureau abandoned the PMTE project, ending its short but useful life.[177]

Voltage and Resistance Standards Based on Quantum Phenomena

A 60-page *NBS Technical Note* entitled *Guidelines for Implementing the New Representations of the Volt and Ohm, Effective January 1, 1990* was published by Norman B. Belecki, Ronald F. Dziuba, Bruce F. Field, and Barry N. Taylor in 1989.[178] Issuance of the guidelines was the culmination of brilliant technical work that extended over 20 years. Laboratories contributing to final values for the new standards encompassed the earth, bringing a revolutionary change to two of the oldest standards of physical measurement.

For a century and a half, electrochemical cells were used as standards of voltage; such cells had provided NBS with its voltage references from the time of its founding. The history of standard cells was described by Hamer in 1965.[179] The most stable type of cell, the Weston cadmium cell, dated from 1891.[180] Enclosed in an H-shaped glass

[176] Kathryn O. Leedy, "Catalog of Federal Metrology and Calibration Capabilities," *NBS Special Publication 546,* first issued, June 1979, 48 pp.; re-issued, September, 1980, 65 pp.

[177] Brian C. Belanger kindly provided historical materials on the PMTE project.

[178] Norman B. Belecki, Ronald F. Dziuba, Bruce F. Field, and Barry N. Taylor, "Guidelines for Implementing the New Representations of the Volt and Ohm," Effective January 1, 1990, *NIST Technical Note 1263,* June 1989, 60 pp.

[179] Walter J. Hamer, "Standard cells, their construction, maintenance, and characteristics," *NBS Monograph 84,* January 1965, 38 pp.

[180] Forest K. Harris, *Electrical Measurements* (New York: John Wiley & Sons, 1952), p. 185. The Weston cell is also described in *NBS Monograph 84,* by Hamer.

container, each column contained an electrode and the cross-tube contained a saturated cadmium sulfate electrolyte. When carefully prepared and aged and maintained at a constant temperature, a group of such cells could provide the same reference voltage (about 1.018 V) within a few microvolts.

The actual value of the volt was derived from the basic SI units of length, mass, time, and electric current. The great care needed to maintain Weston cells at constant temperature and to avoid mechanical disturbance made their calibration a complex and time-consuming process. In its *Calibration Services Users Guide,* the Bureau recommended the use of thermoregulated containers maintained in an upright position for transporting the cells, with a minimum of one week given to stabilizing the cell at NBS, followed by a month of measurements to achieve voltage uncertainties of 1 ppm.[181]

With a similarly venerable history, the NBS standard of dc resistance was embodied in a group of wires. James L. Thomas devised a stable resistance standard for NBS during the 1930s, using bare manganin[182] wire coiled in a stress-free manner in a carefully prepared, sealed atmosphere. A group of 1 Ω Thomas-type resistors was found invariant in resistance within 1 ppm over several years.[183] Although manganin wire had a low temperature coefficient of resistivity, standard resistors were maintained at a constant temperature to minimize resistance changes.

Both Weston cells and Thomas resistors provided standards known as *artifacts*—each copy yielding a slightly different value of the standard depending upon the workmanship of the maker.

The discovery in 1962 of a superconductive tunneling effect by Brian Josephson at the Cavendish Laboratory in Cambridge, England markedly changed the situation for the voltage standard. Josephson received the 1973 Nobel Prize in physics for his theoretical prediction that the flow of electrons between two superconductors connected by a thin insulating layer would be quantized according to the applied voltage. It was found that when a properly prepared Josephson tunnel junction was irradiated with microwave radiation, its current-voltage curve would exhibit steps at precise, quantized voltages characterized by the microwave frequency, by an integer denoting the step number, and by a constant relating the Josephson voltages to the frequency. None of these three numbers involved the identity of the particular Josephson junction, nor even the materials from which it was made.

Realizing the implications of the Josephson effect for voltage standards, scientists from national laboratories in Holland, England, the United States (Barry N. Taylor from NBS), and the International Bureau of Weights and Measures (BIPM) in Paris

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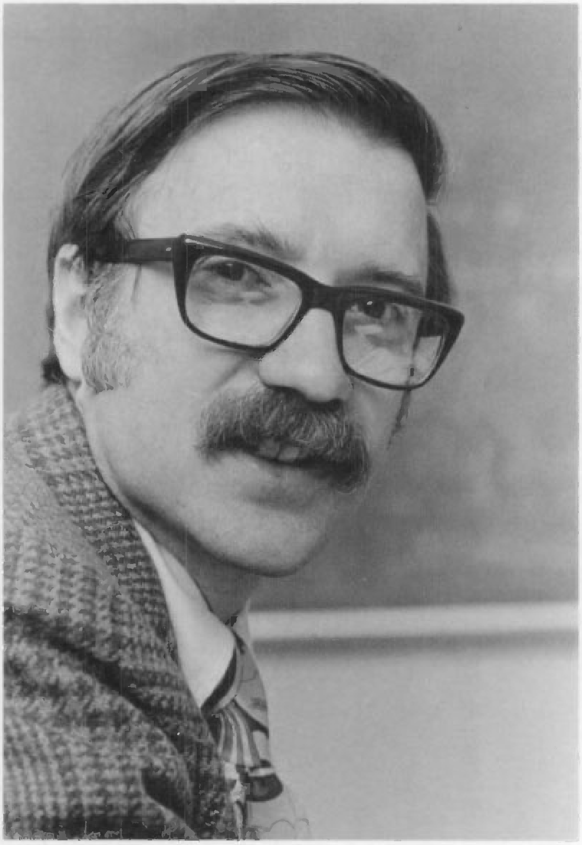
[181] Bruce F. Field, "NBS Measurement Services: Standard Cell Calibrations," *NBS Special Publication 250-24*, October 1987, 52 pp. Also see "NIST Calibration Services Users Guide, 1989," Joe D. Simmons, editor, *NIST Special Publication 250*, January 1989, pp. 114-118.

[182] "Manganin" is an alloy containing approximately 84 % copper, 12 % manganese, and 4 % nickel, chosen for its low temperature coefficient of resistivity and its chemical stability.

[183] Harris, op. cit, p. 213.

formed a working group under the aegis of the BIPM to evaluate the Josephson voltage-to-frequency quotient in units consistent with the International System (SI).[184] In 1988, the International Committee of Weights and Measures suggested that the national laboratories adopt the value of the quotient to be 483 597.9 GHz/V, with the transition to the new voltage standard to take place on January 1, 1990.[185]

While evaluation of the Josephson voltage effect was in progress, Klaus von Klitzing discovered a quantum effect related to measurements of the Hall coefficient in semiconductors.[186] If a high-electron-mobility semiconductor was cooled to a few kelvins above absolute zero and a magnetic flux density of 10 T was applied to it, the two-dimensional electron gas which the system approximated became quantized. As a



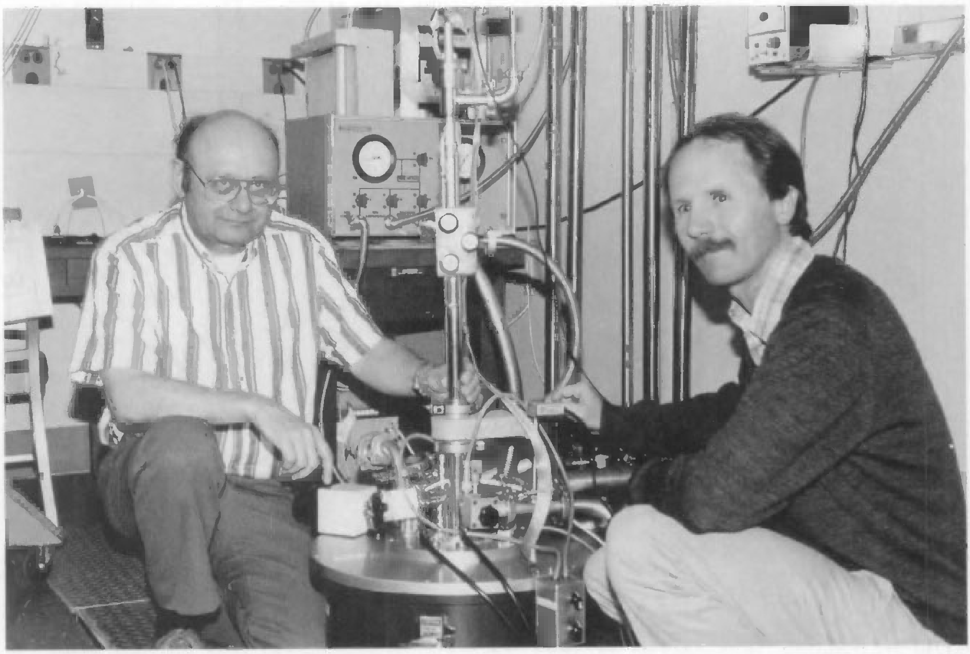
Barry N. Taylor joined NBS in 1970 as chief of the Electrical Measurements Section. An expert in the field of superconductivity, Taylor became a major contributor to the analysis of international physical standards and fundamental constants.

[184] B. N. Taylor and T. J. Witt, "New international electrical reference standards based on the Josephson and quantum Hall effects," *Metrologia* **26**, 47-62 (1989).

[185] B. N. Taylor, "New internationally adopted reference standards of voltage and resistance," *J. Res. NIST* **94**, No. 2, 95 (1989).

[186] K. v. Klitzing, G. Dorda, and M. Pepper, *Phys. Rev. Lett.* **45**, 494-497 (1980).

result, the plot of Hall voltage (at fixed current) vs flux density exhibited plateaus of resistance characterized by a constant which, like the Josephson frequency-to-voltage quotient, was independent of material parameters. The BIPM working group happily accepted the task of determining the best possible value of the "von Klitzing constant" in SI units; following their recommendation during its 1988 meeting, the CIPM selected 25 812.807 Ω as the adopted value. As might have been expected, convincing NBS customers (and their counterparts in other countries) of the wisdom of accepting a change in the volt and the ohm for any reason—let alone on the basis of quantum physics—was a challenging task as well.[187]



Ronald F. Dzuiba and R. E. Elmquist were photographed kneeling on a removable panel above a helium-3 refrigerator and high-field superconducting magnet system, part of a measurement system for the realization of the U.S. ohm using the quantum Hall effect.

[187] K. B. Jaeger and B. N. Taylor, "U.S. perspective on possible changes in the electrical units," *IEEE Transactions on Instrumentation and Measurement,* Vol. IM-36, No. 2, pp. 672-675, June 1987.

Building a New Temperature Scale

Promulgation of the International Practical Temperature Scale of 1968 (IPTS-68) relieved but little of the pressure to improve standard thermometry. The measurement of temperature pervaded all areas of science and engineering, and there was a growing demand for improved range, accuracy, and measurement methods.

Creating an adequate replacement for the IPTS-68 was necessarily a team activity. This was so because of the many features that made up such a scale—many temperature reference points, specialized thermometers for the various temperature ranges, and recipes to define calibration procedures. The devices used to create reference temperatures for thermometer calibration needed to be available commercially or relatively easy to prepare, and they had to be reasonably easy to use at the desired level of precision. Thermometers selected to realize scale temperatures had to be reliable. Choosing appropriate values for the reference temperatures, selecting suitable standard thermometers, and designing workable calibration methods all required considerable work. No one person—no one laboratory—possessed the resources needed to replace the International Practical Temperature Scale of 1968.

Spurred by the discoveries of Evans and Wood, and of Guildner, Anderson, and Edsinger (noted in Ch. 2) that demonstrated flaws in the IPTS-68, scientists at NBS and in many other laboratories set to work to improve it. Realizing that goal would take two decades of hard work.

Provisional 0.5 K to 30 K Scale of 1976 (EPT-76)

Better understanding of the relations between thermodynamic temperatures below 30 K and various laboratory scales, aided by development of new thermometry methods, led to the promulgation of a new Provisional 0. 5 K to 30 K Scale of 1976 (EPT-76). Bureau contributions to the new scale included temperature reference values obtained by Harmon H. Plumb and George Cataland[188] and by George T. Furukawa, William R. Bigge, and John L. Riddle;[189] helium vapor pressure measurements by Roland Gonano;[190] and reference temperatures based on superconductivity, by Robert J. Soulen, Jr, and James F. Schooley.[191]

The new provisional scale proved to be very useful, and it led eventually to the formulation of the International Temperature Scale of 1990 (ITS-90), which defined scale temperatures down to 0.65 K.

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[188] H. H. Plumb and G. Cataland, "Acoustical thermometer and the National Bureau of Standards Provisional Scale 2-20 (1965), *Metrologia* **2**, 127 (1966).

[189] G. T. Furukawa, W. R. Bigge, and J. L. Riddle, "Triple point of argon," pp. 231-243 in *Temperature, Its Measurement and Control in Science and Industry* **4**, 1972, H. H. Plumb, Editor.

[190] R. Gonano, "Isothermal comparisons of He^3 and He^4 vapor pressures," pp. 121-126 in *Temperature, Its Measurement and Control in Science and Industry* **4**, 1972, H.H. Plumb, Editor.

[191] J. F. Schooley and R. J. Soulen, Jr., "Superconductive thermometric fixed points," pp. 251-260 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

Temperatures High and Low

The NBS gas thermometry program is discussed in some detail in Ch. 6. Pursued over a period of several decades, it was a principal contributor to the ability to more accurately realize the thermodynamic temperature scale in the range 0 °C to 660 °C. Temperatures chosen for the ITS-90 in that range were derived mainly from Bureau gas thermometry measurements.

Leslie A. Guildner and Robert E. Edsinger, utilizing a mercury manometer of unique accuracy to measure the pressure of a gas thermometer, found that IPTS-68 temperatures were higher than the gas thermometer temperatures by 0. 025 °C at 100 °C, by 0.044 °C at 231 °C, and by 0.079 °C at 457 °C.[192] These were startling numbers, showing that the IPTS-68 was not nearly so representative of thermodynamic temperatures as had been supposed when it was prepared.

Guildner retired from the Bureau before he and Edsinger completed their plan to operate the NBS gas thermometer to its highest design temperature, 660 °C. James Schooley was given the opportunity to collaborate with Edsinger in finishing the measurements. This he did.[193] The newer results generally corroborated the earlier Guildner-Edsinger findings in the range of overlap between the two experiments, although Edsinger and Schooley found the discrepancies between the IPTS-68 and thermodynamic temperatures to be smaller than had been evaluated earlier. Their values for the differences were 0.03 °C ± 0.002 °C at 230 °C, 0.045 °C ± 0.005 °C at 457 °C, and 0.11 °C ± 0.01 °C at 660 °C.

In constructing the 1990 International Temperature Scale, the international thermometry body—the Consultative Committee for Thermometry (CCT)—took an average of all of the NBS gas thermometry results as the basis for the new scale in the range 0 °C to 660 °C.

Nuclear Orientation Thermometry

The technique of nuclear orientation thermometry was applied by Harvey Marshak to the evaluation of thermodynamic temperatures in the range 0.01 K to 1.2 K. In this elegant method, single crystals of cobalt and holmium were made slightly radioactive by neutron irradiation. The materials were chosen carefully; both elements were naturally monoisotopic and both produced thermometrically useful radioactive samples on irradiation. In his experiments, Marshak carefully aligned the samples in a ^{3}He-^{4}He dilution refrigerator, then measured the anisotropy of the gamma radiation given off by the decay of the radioactive ^{60}Co or ^{166m}Ho atoms with respect to the appropriate crystal axes. Because the nuclear orientation parameters for each system were known,

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[192] L. A. Guildner and R. E. Edsinger, "Deviation of international practical temperatures from thermodynamic temperatures in the range from 273.16 K to 730 K," *J. Res. NBS* **80A**, pp. 703-738 (1976).

[193] R. E. Edsinger and J. F. Schooley, "Difference between thermodynamic temperature and t(IPTS-68) in the range 230 °C to 660 °C," *Metrologia* 26, pp. 95-106 (1989).

Marshak was able to calculate, within about 0.5 %, thermodynamic temperatures indicated by the measured radiation anisotropies.[194] Marshak's work helped the CCT to prepare the ITS-90, as well as laying the foundation for possible extension of international scale temperatures below 0.1 K.

Sealed Triple-Point Cells

During this period, a far-reaching idea occurred to thermometrists. In simplest terms, they decided to rid themselves of the aggravation of dealing with "open" cells for the realization of liquid-state reference points used below room temperature. In this context, "open" cells were those which incorporated a capillary tube for adding and removing gas, or for measuring pressure. For many years, use of such open cells had led to experimental difficulties and irreproducibilities arising from changing purity levels in supposedly "pure" substances.

The model for the sealed cell was the water triple-point device. Made of glass in the form of a long, closed tube with a re-entrant central thermometer well, it contained only water. When the device was cooled sufficiently, a portion of the water would freeze. While the three phases—ice, water, and water vapor—co-existed in thermal equilibrium, the temperature in the re-entrant well remained at 273.16 K, usually within 0.001 K. With no tubes or wires attached, it provided one of the two fundamental defining temperatures for all of thermometry.[195]

George T. Furukawa and William R. Bigge examined several water triple-point cells in preparation for a new scale. They found that all cells of a group of 20 provided the same temperature within 0.0002 °C.

It should be clear that in abandoning open cells one effectively abandoned the use of vapor pressures for thermometry as well as the use of boiling points, since these thermometry schemes required the measurement of pressure as part of the thermometric process. In return for the loss of these measurement opportunities, the thermometrist obtained triple-point temperatures of higher quality.

John Ancsin of the National Research Council laboratory in Canada showed the way to the expanded use of triple points for scale thermometry by measuring the triple-point temperature of oxygen adiabatically.[196] At the Istituto di Metrologia "G. Colonnetti" in Torino, Italy, Franco Pavese used Ancsin's method for the measurement of triple points of gases purified and sealed into high-pressure cells at room temperature. Once prepared, these cells were sealed permanently so that their characteristics—in the absence of leaks—never changed.

George Furukawa brought NBS into the low-temperature-sealed-cell arena with a study of the triple point of purified argon. Constructing three miniature cells with volumes of only 50 ml, Furukawa determined the reproducibility of the triple-point

[194] H. Marshak, "Nuclear orientation thermometry from ~0.001 to ~1.2 K," pp. 95-101 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[195] The reader may recall that the other fundamental temperature reference point was the zero point of the thermodynamic scale. It was inaccessible and thus was not realized in any device.

[196] J. Ancsin, "The triple point of oxygen and its change by noble gas impurities," *Metrologia* **6**, 53 (1970).

temperature, using the methods of adiabatic calorimetry with which he was familiar.[197] He found agreement among the three cells within 10^{-4} K, demonstrating the viability of the technique for low-temperature reference points.

Billy W. Mangum and Donald D. Thornton, a Postdoctoral Research Associate, carefully compared the triple-point temperatures of purified gallium metal obtained from several sources. They found the material to provide an excellent reference temperature near 30 °C. Relatively inexpensive and easy to use in reference cells, the highest-purity gallium (impurities estimated at no more than 1 ppm) offered reproducibility at its triple point within 10^{-4} K.[198] Mangum and Thornton tried both plastic and steel containers for the gallium, and they found no systematic differences.

Mangum and Thornton suggested that the excellent thermal conductivity of gallium, coupled with its ease of use, might make it superior to water as a defining reference temperature for the international scale.[199]

NBS Postdoctoral Research Associate Donald D. Thornton (left) and NBS physicist Billy W. Mangum inspected an assembled gallium triple-point cell. Able to fix an important temperature reference point to within a few ten-thousandths of a degree Celsius, the device was selected by *Industrial Research and Development* magazine as one of the 100 most significant new technical products of 1978.

[197] G. T. Furukawa, "Reproducibility of the triple point of argon in sealed transportable cells," pp. 239-248 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[198] B. W. Mangum and D. D. Thornton, "Determination of the triple-point temperature of gallium," *Metrologia* **15**, No. 4, 201- 215 (1979).

[199] B. W. Mangum and D. D. Thornton, submission to the 12th Session of the Consultative Committee for Thermometry, Paris, May 9-10, 1978.

Radiation Thermometry

Malcolm S. Morse and Ared Cezairliyan teamed with G. M. Foley, a colleague from the Canal Winchester Company, to propose the use of a specially designed, two-wavelength radiation thermometer to measure temperatures in the range 2000 K to 6000 K.[200] They used the device to measure the changing temperatures of rapidly heated specimens on a microsecond time scale. In the analysis quoted, they gave special attention to its accuracy, estimating that the experimental uncertainties of the two channels might range from ±3.7 K to ±30 K. They expected these levels to diminish if the instrument would be used in conjunction with a high-quality laboratory blackbody.

Flame Temperatures

A high-temperature measurement problem rarely faced in the laboratory but common in industrial thermometry was the measurement of flame temperatures. Hratch G. Semerjian and Robert J. Santoro addressed this problem in conjunction with their colleagues P. J. Emmerman and R. Goulard of George Washington University.[201] The technique suggested by this group involved laser tomography, a multi-angular absorption method in which the spatial temperature variation within the flame could be evaluated by computer analysis of the absorption data.

A Resistance Bridge for Thermometry

A notable advance in thermometry using standard platinum resistance thermometers resulted from the development of a new microprocessor-based resistance bridge by Robert D. Cutkosky.[202] Prior to Cutkosky's invention, taking data with resistance thermometers typically was accomplished by manual balancing of a resistance bridge, accompanied by manual recording of resistance values using pen and paper. As soon as his design for an automatic bridge was available, several copies were constructed for use at NBS, providing enormous savings of time and effort through computerized data acquisition and calculation.

The bridges employed five-stage transformers, five standard resistors, and microprocessors that controlled the generation of 15 Hz or 30 Hz measuring signals at a current level variable in steps between 1 mA and 8 mA, the iterative bridge balance, and the display of the unknown resistance to 1 μΩ. The output also could be obtained from a standard computer bus. Two versions of the bridge quickly became "standard"—one with a resistance limit of 32 Ω and a second that could measure resistances up to 100 Ω.

[200] G. M. Foley, M. S. Morse, and A. Cezairliyan, "Two-color microsecond pyrometer for 2000 to 6000 K," pp. 447-452 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[201] H. G. Semerjian, R. J. Santoro, P. J. Emmerman, and R. Goulard, "Laser tomography for temperature measurements in flames," pp. 649-660 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[202] R. D. Cutkosky, *IEEE Trans. Instr. and Meas.* **IM-29**, 330 (1980).

The advent of the automatic resistance bridge was accompanied by efforts to improve the standard resistance thermometer. Along with separate experiments by colleagues in China and Germany, the Heat Division's John Evans sought to create a thermometer design that would allow the resistance thermometer to be used to temperatures as high as 1100 °C—the melting temperature of gold, and, traditionally, the temperature above which radiation thermometry defined the international scale.[203] This proved to be a difficult goal to reach for a variety of reasons, but Evans' thermometer designs helped make the platinum resistance thermometer the standard instrument up to the melting temperature of silver.[204]

Frequency of Visible Light

Continuing the absolute frequency-measurement chain described in chapter 3, Donald A. Jennings, F. Russell Petersen, and Kenneth M. Evenson extended the technique into the range of visible light. The trio determined the frequency of the strong 1.15 μm laser line in ^{20}Ne at 260 THz and lines in iodine at twice that frequency. The frequencies were synthesized in solid-state crystals, $CdGeAs_2$, $AgAsS_3$, and $LiNbO_3$.[205]

An automatic fringe-counting interferometer was developed by John L. Hall and his student Siu Au Lee for the calibration of continuous-wave laser sources during the same period. The two scientists were able to demonstrate uncertainty levels well below 1 ppm with the new instrument.[206]

Calibrating Radio Antennas With the Moon and the Stars

Scientists in the Boulder Electromagnetic Fields Division worked long and hard to develop a system for the calibration of radio antennas and for the minimization of unwanted radio noise. David F. Wait described in 1978 an Earth Terminal Measurement System (EMTS). It could be used to measure earth terminal and satellite parameters such as figure of merit, antenna gain relative to a reproducible reference level, satellite effective isotropic radiated power, ratio of carrier power to operating noise temperature, and noise ulterior flux. Wait's report included troubleshooting hints and software description.[207]

[203] J. P. Evans, "Experiences with high-temperature platinum resistance thermometers," pp. 771-781 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[204] H. Preston-Thomas, "The International Temperature Scale of 1990 (ITS-90)," *Metrologia* **27**, 3-10 (1990).

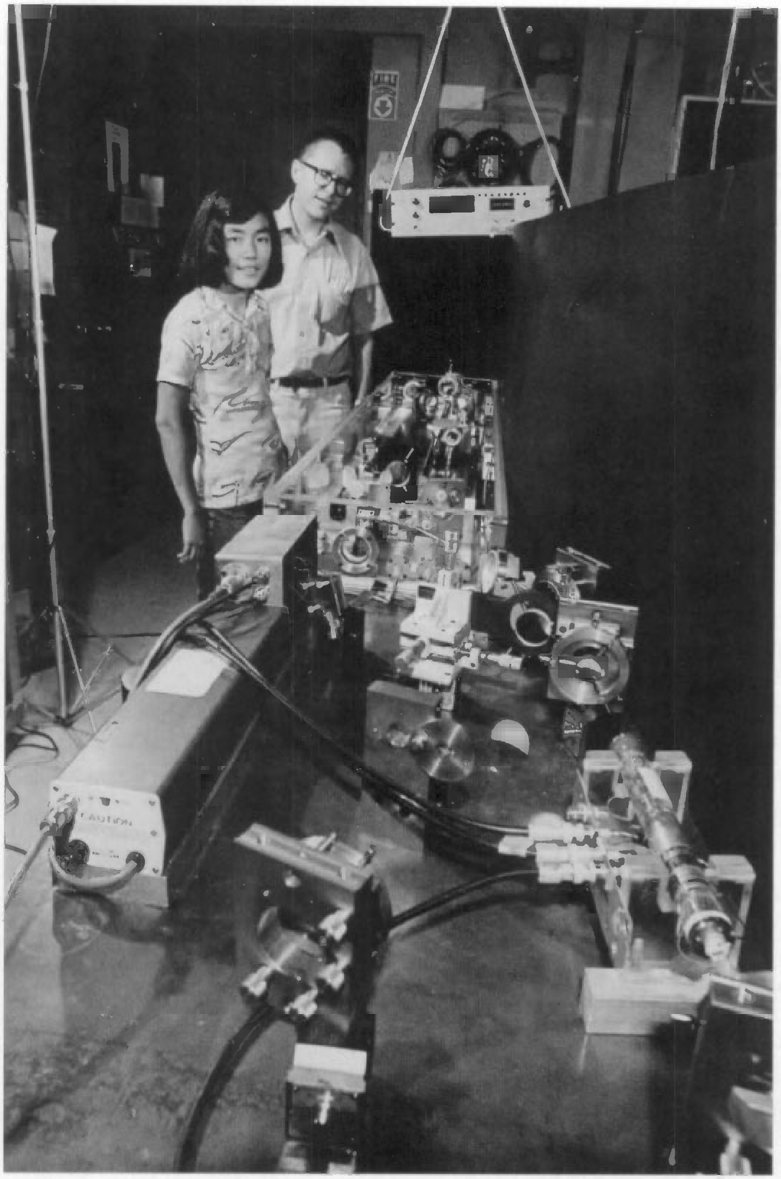
[205] D. A. Jennings, F. R. Petersen, and K. M. Evenson, "Direct frequency measurement of the 260 Thz (1.15 μm) ^{20}Ne laser, and beyond," *Laser Spectroscopy*, Vol IV, H. Walther and K. W. Rothe, editors, (New York: Springer-Verlag, 1979) pp. 41-48.

[206] J. L. Hall and S. A. Lee, "Interferometric real-time display of cw dye laser wavelength with sub-Doppler accuracy," *Appl Phys. Lett.* **29**, No. 6, 367-369 (1976).

[207] D. F. Wait, "Earth Terminal Measurement System operations manual," *NBSIR 78-879*, 268 pp., April 1978.

A computer-driven, automatic resistance bridge was only one of many achievements by NBS scientist Robert D. Cutkosky. His research on electrical standards won him the Gold Medal Award of the Department of Commerce.

By 1984, Wait and William C. Daywitt had worked out methods by which certain stars and the moon could be used as electromagnetic reference sources, relying on the reproducible nature of the radiation emitted by Cassiopiea A and the lunar surface. The sun, a more powerful source, was less reproducible because of its intense and variable solar flares and other activity.



John L. Hall and his student, Siu Au Lee, stood beside their wavelength-calibration interferometer. Dubbed the "Laser Wavelength Meter," the instrument received an IR-100 award from *Research and Development* magazine as one of the most significant new products of 1977.

With the use of the celestial sources, the ETMS noise measurements typically provided 5 % to 15 % uncertainty levels for frequencies in the range 1 GHz to 10 GHz.[208]

A Load-Cell Mass Comparator

Conventional mass comparison balances were mechanical devices capable of weighing up to 30 kg with an uncertainty of about one part per million in the early 1980s. Their cost was about $20,000 and the reading was generally recorded manually by the operator. Electronic load cells were comparatively inexpensive commercial devices that produced electrical signals in response to weight. While the devices were capable of excellent resolution, their response curves tended to drift when the applied load was removed between weighings.

Randall M. Schoonover devised a comparator which made use of the load cell for its low cost, its inherent resolution, and its computer-compatible signal but avoided the drift problem. His solution, in principle, was to maintain the force on the load cell while the test mass was replaced by a reference mass—a principle that was introduced a century ago and is employed in virtually all present-day high-precision balances. Using electronics developed by Robert J. Cutkosky and Richard M. Davis, Schoonover built a prototype of the new device. It exhibited 1 ppm repeatability.[209]

The Texas state metrology laboratory was happy to undertake field tests of the new comparator. Its cost was expected to range from $6000 to $7000; its time for measurement, about 2 minutes, compared with about 15 minutes by the mechanical balance it replaced.

Low-Velocity Airflow Facility

Philip Klebanoff and Patrick Purtell developed a new low-velocity airflow facility that could produce uniform flows at velocities in the range 3 m/min to 1000 m/min, with nearly no turbulence. The two scientists devised a laser-based system to establish a primary standard for the measurement of low air velocities.[210]

One of the first customers for the new facility was the U.S. Bureau of Mines, when a USBM staff member brought to NBS a vane anemometer for calibration to improve its use in monitoring mine ventilation.

Ultimately the earlier air-speed calibration standard, the pitot tube, was replaced by a fiber optic laser Doppler anemometer (LDA) developed by Vern E. Bean and J. Michael Hall. The LDA measured the speed of a flowing stream of air by observing very small particles entrained in the air. Once the measurement technique was worked

[208] D. F. Wait, "Precision measurement of antenna system noise using radio stars," *IEEE Trans. Instrum. Meas.* **IM-32**, No. 1, 110-116 (1983). See also W. C. Daywitt, "Error analysis for the use of presently available lunar radio flux data in broadbeam antenna-system measurements," *NBS Technical Note 1073*, 39 pp., February 1984.

[209] R. M. Schoonover, "A 30 kg capacity high precision load cell mass comparator," *J. Res. NBS* **87**, No. 1, 47-48 (1982).

[210] L. P. Purtell and P. S. Klebanoff, "A low-velocity airflow calibration and research facility," *NBS Technical Note 989*, March 1979, 21 pp.

out, it became a simple matter to calibrate the LDA system; Bean and Hall fixed a vertical tungsten wire of diameter 5 μm at a carefully measured radius on the perimeter of a horizontal disk rotating at a known rate, thus producing an LDA target with a calculable velocity. The uncertainty of the air-speed calibration was reduced by the new method to 0.006 m/s.[211]

Measuring Electromagnetic Interference

A new portable broadband rf radiation field meter developed by Francis X. Ries and E. B. Larsen of the Electromagnetic Fields Division found immediate application in plant safety, in monitoring of power equipment, and in particularly sensitive geographical areas. Electromagnetic interference, arising from sources as ubiquitous as radio and television broadcasts, power transmission, and semiconductor-activated switchgear, produced ac radiation at levels that could injure plant workers, ruin radio reception, and interfere with the operation of sensitive equipment in hospitals or laboratories.

The new NBS field meter was able to detect radiation from 0.2 MHz to 1 GHz, thus covering the spectrum from radio waves to microwaves. The new device was isotropic in its response, thanks to the incorporation of three small, mutually orthogonal dipole antennas. Dubbed the EFM-5 Electric Field Monitor, the probe could sense field intensities in the range 1 V/m to 1000 V/m.[212] The usefulness of the new meter was so plain that one manufacturer began immediately to design a commercial version.

A New High-Voltage Calibration Service

In 1985, Martin Misakian published an *NBS Technical Note* describing a new calibration service for high-voltage dividers and high-voltage resistors. The new service was important to researchers in such fundamental studies as elementary-particle physics, to operators of x-ray and other high-voltage equipment, and to the power industry.

In principle, the measurement system was simple—a guarded Wheatstone-bridge apparatus. In practice, the laboratory gave the appearance of a science-fiction movie set, with its large high-voltage insulators. Misakian was able to offer calibrations with uncertainty levels below 0.01 % for equipment useful at voltages from 10 kV to 150 kV.[213]

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[211] Vern E. Bean kindly provided information on the new laser Doppler anemometer calibration system.

[212] E. B. Larsen and F. X. Ries, "Design and calibration of the NBS isotropic electric-field monitor (EFM-5), 0.2 to 1000 MHz," *NBS Tech. Note 1033*, March 1981, 104 pp.

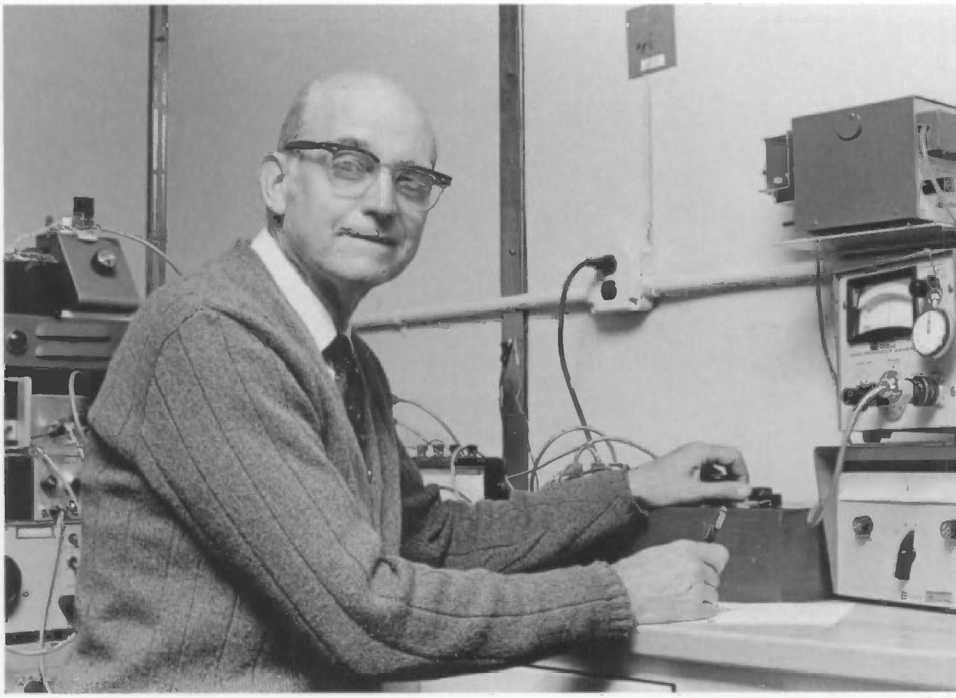
[213] M. Misakian, "High voltage divider and resistor calibrations," *NBS Technical Note 1215*, July 1985, 25 pp.

Martin Misakian prepared to evaluate the performance of a dc high-voltage power supply used for calibrating high-voltage dividers at NBS.

A Prize for Hermach

The Institute of Electrical and Electronics Engineering (IEEE) recognized a lifetime of contributions to electrical standards by Francis L. Hermach by presenting him with the Morris E. Leeds prize during a 1976 meeting. In one of Hermach's many projects, he developed the concept of using thermal converters as transfer standards in the measurement of ac-dc voltage differences. He made careful studies of the physical bases for the frequency-dependence found the devices.

The Leeds prize was not Hermach's first honor. Joining the NBS Electricity Division in 1939, he became chief of the Electrical Instruments Section in 1963. In recognition of his achievements in electrical standards and instrumentation, he was elected to fellowship in the IEEE and in the Instrument Society of America (ISA). In 1970, Hermach received the Silver Jubilee Award from the ISA for "his contributions to the accuracy of current and voltage measurements."



Francis L. Hermach of the Electricity Division in the National Bureau of Standards Institute for Basic Standards was awarded the prestigious 1976 Morris E. Leeds prize of the Institute of Electrical and Electronics Engineers for outstanding contributions to the field of electrical measurements.

Technology of Buildings and Other Structures

The Bureau's building research and fire research groups often were asked to form teams to investigate natural disasters, structural failures, and fires in addition to the many in-house projects in both groups. In some cases, the investigations were sensitive in nature, having been requested by highly placed officials. National Engineering Laboratory Director John Lyons referred to such cases as "hot potatoes." The conduct of the investigations themselves, their conclusions, and any resulting reports were carefully monitored by senior managers, designated specialists, and legal counsel.

Some of the "hot potatoes" are discussed in this section; others may be found elsewhere in the volume. Such cases added spice to the lives of the investigators and gray hairs to the heads of the senior managers.

Designing Structures for Wind Loads

The safe and economical design of structures for wind loads required meaningful estimates of maximum wind speeds. Historically, this design problem was a difficult one for designers. They could build using any of several estimates of extreme wind speeds, balancing maximum safety and minimum cost.

NBS scientists Emil Simiu of the Center for Building Technology and James Filliben of the Center for Applied Mathematics considered the problem in collaboration with Jaques Bietry, a French colleague, using a new approach. They employed the methods of Monte Carlo calculation to analyze existing wind data in non-hurricane areas for comparison with the historical models. Their results clearly supported the "Gumbel" model—one that limited the prediction of high-velocity winds to lower values than other models.[214]

The results obtained by the three scientists led to a change in standardization practices and building design throughout the world. Particularly affected was the area of statistical analysis. Their ideas became part of an engineering text, co-authored by Simiu, describing the fundamental effects of wind on structures.

Structural Disasters

During an evening dance contest on Friday, July 17, 1981, at the Hyatt Regency Hotel in Kansas City, Missouri, two suspended walkways—carrying patrons who were watching the scene or traversing an atrium high above the festivities—gave way and fell into the mass of people below. It was the deadliest structural disaster in American history—113 dead, 186 injured. Three days later, Senator Thomas F. Eagleton and Mayor Richard L. Berkley asked NBS to help discern the cause of the catastrophe. The Bureau was ready, willing, and able to help.

A team of scientists and engineers from the Center for Building Technology in Gaithersburg and the Center for Materials Science in Boulder was assembled immediately. The team included Richard D. Marshall, Edward O. Pfrang, Edgar V. Leyendecker, Richard P. Reed, Maurice B. Kasen, and T. Robert Shives; they reached the scene the next day. The group examined the atrium area and visited a warehouse where authorities had temporarily stored debris from the collapse.

Until certain legal questions could be answered, NBS access to some of the materials needed for analysis of the disaster was delayed. But eventually Bureau scientists and engineers were able to examine the fallen walkways and remove critical portions of the debris for testing in their own laboratories. On the basis of the study, they were able to describe the course of events on the fateful evening in terms of material strengths, design criteria, and construction techniques, comparing the actual strength of the walkways with that required by the Kansas City building code.[215] Theirs is an arresting analysis of a disaster that was inevitable once construction of the walkways was complete.

The hotel was built with a tall atrium between a residential tower and an area that encompassed registration, dining, and other facilities. Three walkways traversed the atrium at different levels. The fourth-floor walkway was directly above the second-floor walkway, while a third-floor walkway crossed at some distance from the other

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[214] E. Simiu, J. Filliben, and J. Bietry, "Sampling errors in the estimation of extreme winds," *J. Structural Division, Amer. Soc. of Civil Eng.* **104**, No. ST3, March 1978.

[215] Richard D. Marshall, Edward O. Pfrang, Edgar V. Leyendecker, R. P. Reed, M. B. Kasen, and T. Robert Shives, "Investigation of the Kansas City Hyatt Regency walkways collapse," *NBS Building Science Series 143*, May 1982, 350 pp.

two. Three pairs of threaded steel rods anchored in the ceiling of the atrium (hanger rods) supported the third-floor walkway, and another three pairs supported the fourth-floor walkway. Each pair of hanger rods actually supported a cross-beam, with the walkway itself lying atop the beam; the rods passed through holes in the beams which then rested on large steel washers and nuts. The way the walkway supports were installed turned out to provide an inadequate margin of safety, according to the testing done by the NBS team and the requirements of the Kansas City Building Code.

Although the original design of the hotel called for the fourth-floor walkway hanger rods to be long enough to also support the second-floor walkway, the actual construction resulted in the use of a second set of hanger rods anchored to the fourth-floor walkway beams. This deviation from the original design was a fatal error, for it effectively doubled the load on each of the fourth-floor cross-beams, causing the washer-nut connection on one of the fourth-floor beams to pull through its hole when some 40-60 people gathered on the walkways to watch the dancing.

The NBS analysis was painstaking. Micrographic analysis of the support hardware and strength testing of the beam assemblies allowed the team to estimate the load-bearing capability at each of the hanger-rod positions. The flawed design of the cross-beam, washer-and-nut connections, coupled with the unwise suspension of the second-floor walkway from the one above it, resulted in a load-carrying capacity barely strong enough to bear the weight of the walkways themselves—no more than half the capacity demanded by the local building code. The recipe for disaster required only the ingredient of a certain amount of extra weight, provided on a summer evening by the attraction of a dance contest.

Earthquake!

The year 1977 saw the heaviest damage from earthquakes in four centuries, according to seismic experts. It was thought that the problem might not ease anytime soon.

Congress reacted to the perceived increase in the danger to U.S. cities with passage of the *Earthquake Hazards Reduction Act of 1977* (PL 95-124). The Act directed the President to establish and maintain a coordinated earthquake hazards reduction program, based upon improved structural design and construction methods, improved prediction techniques, and improved land-use policies. The Bureau was asked to participate in data-gathering, testing, and analysis of earthquake damage and improved construction methods.

Following are only two examples of several earthquake investigations by NBS during Ambler's tenure.

An earthquake demolished many buildings in downtown Bucharest, Romania, on March 4, 1977. Two NBS engineers led a U.S. study team to the site, where they gathered information on the types of buildings that were damaged, evident sources of the damage, and the effectiveness of earthquake-resistant construction in Bucharest. The Bureau team was directed by the Office of Foreign Disaster Assistance of the Agency for International Development.

The NBS report, written by George S. Fattal, Emil Simiu, and Charles G. Culver, ran to some 160 pages and included more than 100 photographs illustrating the damage caused by the earthquake.[216] The report also recommended methods for restoration of some of the structures, as well as suggestions for building practices for improved seismic resistance. The eventual U.S. offer of assistance to Romania was based, in part, on the NBS recommendations.

Graphic images resulting from a severe earthquake (8.1 on the Richter scale) that rocked Mexico City on September 19, 1985, stayed in the minds of many who saw—in news reports or first-hand—the extent of the damage. More than 6,000 people were killed or could not be found; some 14,000 were injured; places of employment were lost by 150,000. Contributing to the human suffering, more than 5,000 buildings were damaged more or less severely, nearly 700 of those partially or completely collapsing. Streets and water mains were shredded, along with many telephone lines. Total economic damage was expected to approach $4 billion.

Large as it was, the disaster could have been worse. The earthquake occurred at 7:19 am, before many people had left their homes to work in the medium-tall buildings that suffered some of the worst damage. And the damage, mimicking the destructive pattern of a Richter 7.5 quake that struck Mexico city in 1957, was selective. Although buildings in the 5-20 story range suffered major damage, many nearby buildings and all buildings taller than 30 stories escaped.

A team of five scientists—William C. Stone and Felix Y. Yokel of NBS and Mehmet Çelebi, Thomas Hanks, and Edgar V. Leyendecker of the U.S. Geological Survey—was dispatched under the aegis of the Interagency Committee on Seismic Safety in Construction to provide technical advice to rescuers and to assess the nature and extent of the structural damage with respect to minimizing earthquake damage in the future.[217] Professors from the Institute of Engineering of the University of Mexico assisted the U.S. team with information on subsoil conditions, building codes, and other information on Mexico City.

The team observed that most of the destruction was confined to an area of the city that once lay beneath a lake, where the soft surface land subsided continuously and noticeably with time. The substantial ground motion was amplified by the nature of the subsoil. The group analyzed the failures of buildings and their foundations in terms of existing seismographic records and obvious differential displacement of sidewalks and pavement around buildings. Many details of tilted and overturned structures showed the influence of the subsurface on the extent of earthquake damage.

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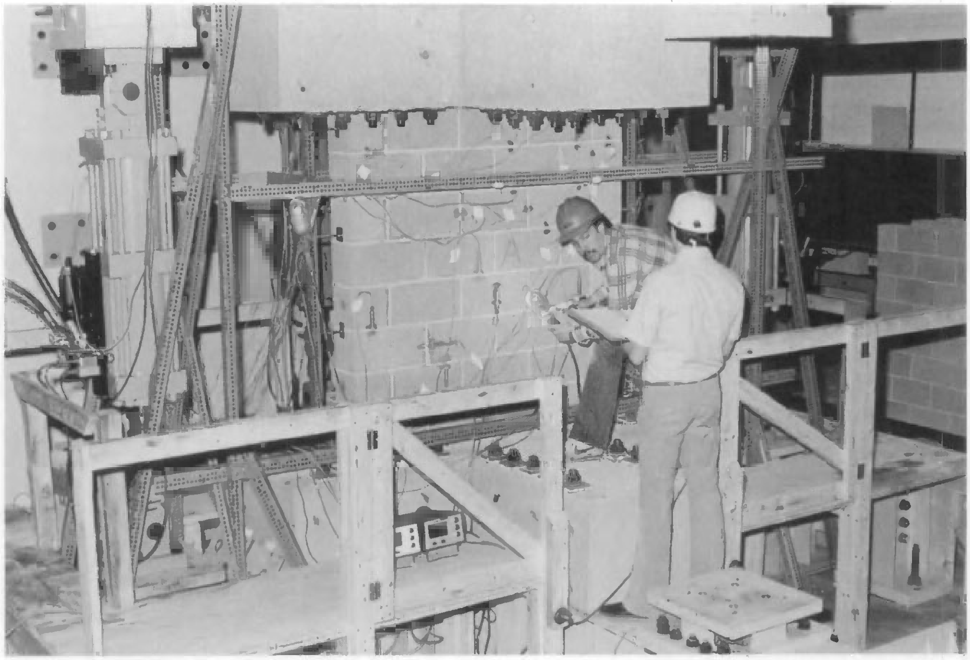
[216] G. S. Fattal, E. Simiu, and C. G. Culver, "Observations on the behavior of buildings in the Romania earthquake," *NBS Special Publication 490,* 168 pp., September 1977.

[217] William C. Stone and Felix Y. Yokel of NBS and Mehmet Çelebi, Thomas Hanks, and Edgar V. Leyendecker, "Engineering aspects of the September 19, 1985 Mexico earthquake," *NBS Building Science Series 165,* May 1987, 207 pp.



Engineers from the NBS and the Bureau of Mines collaborated in earthquake hazards prevention research, using a special tri- directional test facility at the NBS Center for Building Technology. In this photograph, engineers studied the behavior of masonry walls under shear stress.

On the basis of previous experience with earthquake damage from the relatively close Middle American Trench area that ran along the Southwest coast of Central America, the Mexico City authorities long ago issued special building codes intended to minimize earthquake damage. Structures were to be built so as to move as a unit, with minimum foundation motion. Nevertheless, not even the newest buildings escaped damage.

The disaster team from the U.S. obtained an enormous amount of detailed information about the response of a variety of structures, mainly buildings, to the well-documented forces resulting from the Mexico City earthquake. For example, a 43-story steel frame building apparently survived because its natural vibration period was well outside the resonance period of the earthquake, so that it was "detuned" from major structural damage. In other cases, buildings built close to each other suffered damage from "pounding" as they swayed and made contact with each other in response to the earthquake.

Stress-Wave Analysis of Concrete

In 1983, Nicholas Carino and Mary Sansalone of the Center for Building Technology initiated a research project to develop a stress-wave-propagation technique for locating defects within concrete structures. While the use of stress waves was a familiar practice in the non-destructive evaluation of metals, little success had resulted from previous efforts in concrete analysis.

With colleagues in CBT and acoustics experts from the Center for Manufacturing Engineering, Carino and Sansalone took advantage of advances in numerical simulation methods, transducer technology, and signal processing to propose a new analytical technique which they called the "impact-echo" method.[218]

The new method was a big hit. It was adopted as an approved test method for thickness measurement by the American Society for Testing and Materials (C 1383, 1998), and it formed the basis for new commercial products for use in the Nation's highway industry.

Projects in Preservation

During 1980, the White House received a much-needed face-lift with help from NBS.

Paul Campbell, Gerald Sleater, and Mildred Post of the Structures and Materials Division, Center for Building Technology, were called in during 1978 by the National Park Service for advice on cleaning and painting the exterior of the venerable residence. For nearly 2 years, the NBS team evaluated the exterior surface of the building's walls, tested certain points and cleaning methods, and made their recommendations.

Restoration began in 1980, with stripping of the paint on the building's east side, where the paint had suffered the most damage. Following the Bureau recommendations, the paint on the east side was stripped chemically and the entire building hosed with a high-pressure water spray. Defects in the exterior masonry were patched and allowed to cure, and a primer coat of paint was applied to the east side. Finally, an alkyd-based paint was applied to the entire structure. Interestingly, the paint color chosen by the White House staff was not white, but a softer cream color to make the building "more appealing" by day and night.[219] Bureau scientists undertook other investigations for the National Park Service as well, most of them of a geophysical nature.

Helping OSHA

During construction of a five-story condominium building in Cocoa Beach, Florida in March 1981, the building suddenly collapsed, killing 11 workers and injuring two dozen others. Occupational Safety and Health Administration officials asked representatives of the Bureau's Center for Building Technology to investigate the disaster in order to determine its cause.

An experienced team—Hai S. Lew, Nicholas J. Carino, S. George Fattal, and Martin E. Batts—responded with on-site inspections, laboratory tests, and analytical studies. The team concluded that the construction had proceeded without full attention to certain factors, among them:

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[218] M. Sansalone and N. J. Carino, "Detecting delaminations in concrete slabs with and without overlay using the impact-echo method," *ACI Materials Journal* **86**, No. 2, March-April 1989, pp. 175-184.

[219] "How do you keep the White House white?," *NBS Standard,* Vol 25, No. 18, p. 5.

Chemist James R. Clifton of the Bureau's Center for Building Technology headed an NBS project on preservation technology which was initiated at the request of the National Park Service. In the accompanying photograph, Clifton (left) and Paul Brown prepared an adobe specimen for microscopic examination by impregnating it with methyl methacrylate. The inset shows a cross section of an adobe specimen.

- Non-uniform concrete was used in the construction, and its strength was not up to code.
- Positioning of the reinforcing rods in the floor sections did not allow specified shear resistance criteria to be met. No test of this parameter had been performed, because the test had not been specified in the building design.

The result of the faulty design and construction led to failure of the building after the fifth floor was installed. The fifth floor collapsed, carrying with it all the lower floors.[220]

OSHA also requested NBS assistance in ascertaining the cause of the collapse of a highway bridge ramp in East Chicago, Indiana, which killed 13 workers and injured 17 others.

In both cases, NBS tests showed an increasing need for improved test methods for evaluating the strength of structures during construction.

Measuring Insulating Values

The heat-retardant value of various types of thermal insulation received increased attention as the costs of all building materials spiraled upwards during the 1980s. At the request of the Federal Trade Commission and the Department of Energy, NBS scientists Chock In Siu and Charles Bulik designed and built a new device for improved measurement of batts of thermal insulation.

The new apparatus, a specially designed guarded hot plate, provided greatly improved precision in the measurement of the thermal conductivity of the batts, the basis of "R" values in the construction industry. Heat was applied to the samples from a line heat source, with the temperature of the surrounding guard ring set to minimize transverse energy loss. The apparatus could be used at any temperature within the range 250 K to 400 K.[221]

Using the new device, the National Engineering Laboratory initiated production of standard samples of insulation with thicknesses ranging from 25 mm to 150 mm for use as references for the FTC. For the first time, R-values for all thicknesses of thermal insulation materials could be based upon actual measurements.

Health & Safety Projects

We illustrate Bureau projects relating to health and safety with an octet of programs diversely based—upon superconductivity, dentistry, high-frequency sound, ionizing radiation, mercury detection, metallurgy, thermometry, and prosthetics.

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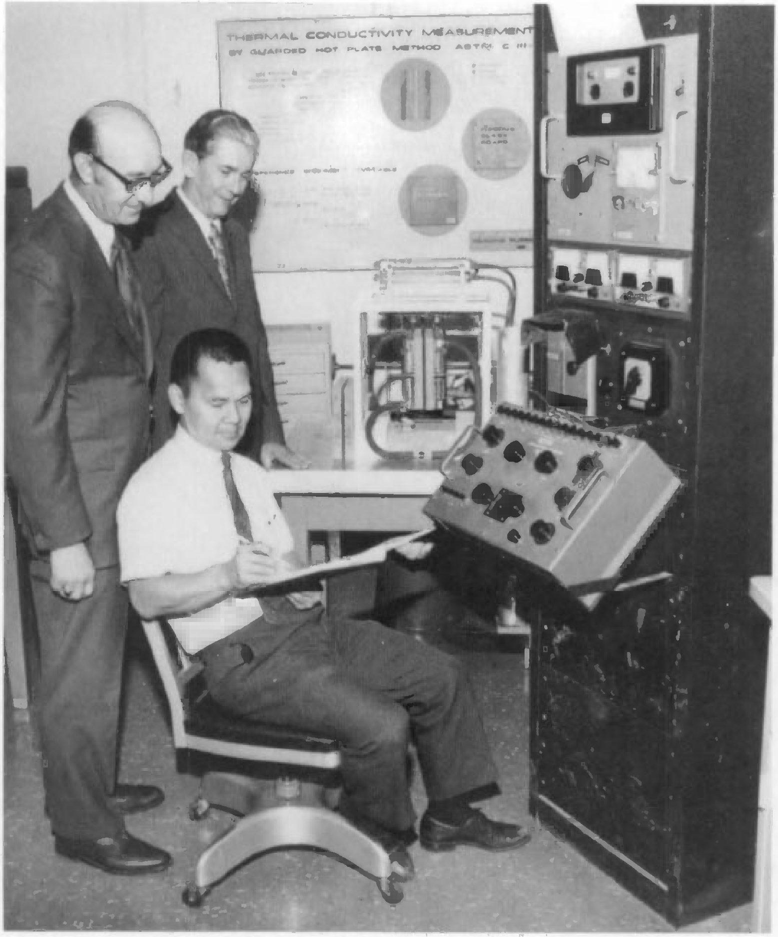
[220] H. S. Lew, N. J. Carino, S. G. Fattal, and M. E. Batts, "Investigation of construction failure of Harbour Cay condominium in Cocoa Beach, Florida," *NBSIR 81-2374*, September 1981, 138 pp.

[221] M. C. I. Siu and C. Bulik, "National Bureau of Standards line-heat-source guarded-hot-plate apparatus," *Rev. Sci. Inst.* **52**, No. 11, 1709-1716 (1981).



Frank J. Powell (standing on the left), Chief of the NBS Thermal Engineering Systems Section, and section colleague Thomas W. Watson watched as the Bureau's Chock I. Siu operated a guarded hot-plate apparatus (on table) to determine the thermal conductivity of insulation.

Magnetoencephalography

In Ch. 2, we noted that James E. Zimmerman of the Boulder Cryogenics Division was a pioneer in the use of superconducting quantum interference devices (SQUID) for medical diagnostics. During the late 1970s, Zimmerman carried his studies further into medical research with the collaboration of M. Reite of the University of Colorado Medical Center, J. Edrich of the University of Denver, and J. T. Zimmerman of the University of Colorado department of Psychology.

The experiments undertaken by the group went by the generic title of magnetoencephalography, the recording of magnetic activity in the brain. The SQUID served as a magnetic gradiometer, able to detect local variations in the intensity of magnetic fields produced by brain activity. For improved sensitivity, observations were performed in a shielded room in the Boulder laboratory. The magnetic measurements of brain activity appeared to be capable of better spatial precision on the skull of human subjects than electroencephalography.

To test brain response to auditory signals, the team presented clicking sounds to four subjects through earphones. Within less than a half-second after receiving a sound pulse, each subject exhibited a magnetic response that was detectable by the apparatus near the area on the scalp thought to correspond most closely to the primary auditory cortex of the brain. It was the first demonstration of auditory evoked response by magnetoencephalography.[222]

Dental Work at NBS

Collaboration between the American Dental Association (ADA) and NBS continued without interruption from 1928, when the first ADA research associate, Norris O. Taylor, arrived. The productivity of the collaboration was outstanding.

Almost 50 years later, in 1977, there were nine NBS employees working as members of the Dental and Medical Materials Section of the Polymers Division, 22 research associates of the ADA Health Foundation Research Unit, and individual associates from the U.S. Navy, the Air Force, and the National Association of Dental Laboratories. Funding was provided by the ADA foundation, by NBS, and by agencies such as the National Institutes of Health.

During its first half-century, the collaboration produced 25 standards for dental materials and more than 600 scientific papers. Among the items of apparatus commonly used in 1977, the high-speed-turbine hand drill and the panoramic x-ray machine were developed at NBS. Composite restorative dental materials were developed at the Bureau as well.

During World War I, Wilmer Souder, an NBS physicist working in conjunction with the U.S. Army, began evaluating the properties of dental amalgams. In 1926 the work led to the first dental specification by the ADA.

George Paffenbarger was the Senior Research Associate in 1977; with Nelson Rupp, chief of Clinical Research for the ADA foundation, he updated the amalgam specification to eliminate from common use those amalgams that tended to produce inferior results. The goal of amalgams research, to make the restoration last the entire lifetime of the patient, was near, said Rupp; only slight differences in dental handling limited the service life of amalgams.

A 1956 collaboration, led by Ray Bowen—in 1977 still part of the research team at NBS—developed silica-resin composites that became standard materials for filling pits and fissures in teeth.

[222] M. Reite, J. Edrich, J. T. Zimmerman, and J. E. Zimmerman, "Human magnetic auditory evoked fields," *Electroencephalogr. Clin. Neurophysiol.* **45**, 114-117 (1978). A simplified discussion of this work can be found in *Dimensions/NBS,* February 1978, pp.19-21.

In 1974, Walter Brown published a new theoretical discussion of tooth decay; his idea was that decay initiated slightly below the tooth surface with a process of demineralization. [223]

Richard Waterstrat, chief of Dental Metallurgy, sought an effective substitute for gold in dental restorations. Gold constituted one of the principal components of restoratives that involved the fusing of porcelain to metals. The high cost of gold provided the motivation for Waterstrat's efforts. His work led him to become an expert on the phase diagrams of alloys of noble metals with less expensive elements. Properties such as toxicity and response to the chemistry of the mouth complicated Waterstrat's metallurgical problems.

In 1977, Curtis Mabie was chief of dental ceramics. His work focused on porcelain and other ceramic restoratives. An example of this effort was an attempt to render ceramic fillings opaque to x rays, so as to distinguish them from cavities.

Gerhard Brauer of the NBS dental group prepared a review of the use of polymers in dentistry for the construction of dentures, plastic teeth, and impression materials. He pointed out the advantage of liners that bonded securely to teeth, and discussed research in progress.[224] Brauer received the Department of Commerce Gold Medal award in 1975 for his work in dental research.

Bonding dental resins to dentin was an objective of research by Joseph M. Antonucci. He sought to replace the "acid-etch" process with monomers that co-polymerized with dentin.[225]

Crystallographer Leroy W. Schroeder, an American Dental Association Research Associate, was photographed with models of glaserite, used in studies of the crystalline structure of the apatites found in teeth.

[223] W. E. Brown, "Physicochemical mechanisms of dental caries," *J. Dent. Res.* **53**, No. 2, 204-216 (1974).

[224] G. M. Brauer, "Polymers in dentistry," Chapter 5 in *Dental Materials Review*, R. G. Craig, editor (Ann Arbor: University of Michigan Press, 1977), pp. 78-111.

[225] "New technique for dental restorations," *Dimensions/NBS,* April 1977, p. 22.

Medical Diagnosis With Ultrasound

High-frequency sound waves were used in many ways at NBS. Some of these involved non-destructive evaluation. A special category of non-destructive evaluation turned out to involve ultrasonic medical diagnosis, a new field that came into its own during the tenure of Ernest Ambler as director of NBS.

During May 1975, an international seminar on ultrasonic characterization of tissue was held at the Gaithersburg campus of NBS. The seminar was chaired by Melvin Linzer of the Bureau's Inorganic Materials Division.[226] It was co-sponsored by NBS, the National Institutes of Health, and the National Science Foundation. Some 22 papers were given during the meeting; they focused on experimental methods. Participants represented research hospitals, universities, government agencies, and private firms. In a keynote talk, G. B. Devey of the National Science Foundation traced the beginnings of NSF support for research on medical ultrasonics and progress towards the goal of bringing the techniques to clinical medicine. The seminar played an important role in disseminating new information on the status of the field.

A *Second International Symposium on Ultrasonic Tissue Characterization,* again co-sponsored by NBS, NIH, and NSF, and held at NBS from June 13-15, 1977, brought forth further instrumental details of ultrasonic techniques. Included among the 50-odd papers were specifics on some of the medical uses of ultrasound. These included the fact that, properly administered, ultrasound did not damage tissue during diagnostic use. Birth defects, brain disorders, heart disease, tumors of the breast, liver anomalies, and bone composition, all of these were diagnosed using ultrasound.

One contribution to the second symposium was offered by Melvin Linzer in collaboration with Stephen I. Parks, S. J. Norton, F. P. Higgins, and R. W. Sheidler, and their colleagues from NIH, T. H. Shawker and J. L. Doppman. Their paper described progress in developing at NBS a comprehensive analysis system for tissue, based upon the use of ultrasonics. Techniques considered for the system included computer-assisted tomography, opto-acoustic testing of imaging, transducer calibration, and sensitivity enhancement through signal averaging. Portions of the new system were tested and found satisfactory in the Clinical Center of the National Institutes of Health.

Safe Use of Ionizing Radiation

Lauriston S. Taylor took advantage of an opportunity to lecture on one of his specialties, radiation safety, on March 1, 1976. Taylor was a veteran member of NBS (his service to the Bureau began in 1927 and extended to 1965) and a national spokesman for radiation-related public safety problems. He was chief of the Bureau's radiation physics activities from 1950 to 1962, he served the National Academy of Sciences for 4 years in emergency planning, and during 1976 he was President of the National Council on Radiation Protection and Measurement. As keynote speaker

[226] "Ultrasonic Tissue Characterization: Proc. of a seminar held at NBS, May 28-30, 1975," Melvin Linzer, editor, *NBS Special Publication 453,* 288 pp., October 1976.

for the NBS-sponsored symposium on Measurements for the Safe Use of Radiation, Taylor reminded his audience of a few facts from the history of radiation safety, as well as some of his own thoughts on the topic.

First to be mentioned was the idea of traceability of measurement standards; it would be of little benefit to patients at a hospital if the radiation-measurement capability of NBS could not be transferred at an acceptable level to that hospital. Taylor was involved in inter-laboratory comparisons of x-ray standards as early as 1931.

Early medical x-ray dosimetry involved color-change chemicals, photosensitive films, and ionization chambers. Taylor traced the history of x-ray standards activities to the mid-70s, noting the availability of 5 % accuracy for patients in hospitals with the best measurement practices.

Taylor suggested continuing maintenance of basic radiation-safety measurements, continuing measurement assurance with organizations that place people in radiation situations, and continuing development of accurate and reliable field instruments.[227]

A New Mercury Monitor

Industrial workers encountered mercury less frequently during the mid-70s than they did in earlier times,[228] but NBS nevertheless found a ready audience for its development of an improved mercury monitor.

National Institute of Occupational Safety and Health (NIOSH) safety standards limited exposure to mercury vapor to 0.05 mg/m^3 during an 8-hour workday. Eugene P. Scheide and John K. Taylor developed a sensitive, portable, inexpensive device that measured the total amount of mercury exposure over a workday.

The device was based upon the principle of the microbalance. It employed frequency measurement to indicate the amount of mercury encountered in its active components. The two scientists found that they could evaporate a gold layer on the surface of a piezoelectric crystal of quartz. Gold amalgamated easily, absorbing mercury as room air was drawn past the crystal; as the mercury accumulated, the natural frequency of vibration of the quartz changed. A simple formula related the amount of mercury absorbed to the change in resonant frequency of the dosimeter.

Perhaps best of all, a simple baking procedure could remove as much as 90 % of the mercury from the dosimeter after it was read. The sensor/air-pump system could readily be worn on a worker's clothing.[229]

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[227] Lauriston S. Taylor, "A saga of radiation safety," *Dimensions/NBS,* May 1976, pp. 7-9, 21.

[228] Madeleine Jacobs, in "NBS develops new mercury monitor, *Dimensions/NBS,* January 1976, pp. 3-5, noted that the "Mad Hatter" of Lewis Carroll's "Alice in Wonderland" derived from the visible symptoms exhibited by workers in the hat industry when felt and fur processing involved the use of mercury in large quantities.

[229] E. P. Scheide and J. K. Taylor. "Piezoelectric sensor for mercury in air," *Environ. Sci. Technol.* **8**, No. 13, 1097-1099 (1974).

NBS chemists John K. Taylor (left) and Eugene P. Scheide discussed the portable mercury monitor that they developed to help public health officials determine whether a worker was exposed to hazardous levels of mercury.

Safety From Burning Metals

Metal combustion studies at NBS/Boulder had as their goal the elucidation of the basic mechanisms involved in the burning of metals in the workplace. A research team of John L. Moulder C. C. Runyan, and Alan F. Clark undertook the project at the suggestion of a triplet of agencies—the Department of Transportation, the National Aeronautics and Space Administration, and the U.S. Air Force Office of Scientific Research.

Metals of special interest were involved in the transport of liquefied or gaseous oxygen. Any tendency for metal to burn—to oxidize, usually—would be enormously speeded up by the presence of oxygen in large quantities. One example of such a disaster was the explosion of a liquid oxygen tank truck in Brooklyn, which killed or injured more than 30 people.

The research team prepared a test fire by igniting 100 g samples of steel in an oxygen pressure tank, then dropping them on other metals. All experiments were conducted by remote control, with video monitors. Filming at a rate of 500 frames per second, they followed the details of combustion. Reaction rates could be monitored by weighing the samples during combustion. Radiation thermometers and spectrometers provided temperature and spectral data, showing the presence or absence of intermediate species.[230]

[230] A. F. Clark, J. C. Moulder, and C. C. Runyan, "Combustion of bulk titanium in oxygen," paper in *15th International Symposium on Combustion* (Pittsburgh: The Combustion Institute, 1974) pp. 489-499.

Medical Thermometry

From the hand on the fevered brow, to the mercury thermometer under the tongue, to the electrical thermometer encased in a throw-away protector, medical and clinical thermometry gained both speed and accuracy.

In 1973, the NBS Heat Division initiated a program in Medical Thermometry, headed by Billy W. Mangum. At that time, the most accurate thermometer available to the medical profession was uncertain by 0.3 °C in terms of the International Practical Temperature Scale of 1968. Standard thermometers and a temperature reference point based on the melting point of purified gallium, subsequently developed in the Medical Thermometry program, reduced the previous uncertainty level by a factor ten. The new thermometers were made part of the Standard Reference Materials program and given the designations SRM 933 and SRM 934. They were used primarily to calibrate new, miniature electrical-resistance thermometers—thermistor thermometers or tiny platinum resistance thermometers. While they were very sensitive, the new thermometers needed re-calibration on a regular basis.

Working with thermistor manufacturers, Mangum and his co-workers helped to develop types of thermistor thermometers of exceptional stability—some showing drift rates as small as 0.005 °C per year.

To provide thermometry for body tissue under high-frequency irradiation, the group studied the use of ordinary radiation thermometry or non-metallic thermometers. A birefringent-crystal thermometer, $LiTaO_3$, connected to its power source and readout device by optical fibers, showed promise for contact thermometry in irradiation experiments.[231]

New Body Parts for Old

In 1975, about 1 million foreign objects (implants) were surgically inserted into human patients. These consisted of nails and screws, plates and joints, heart valves and synthetic blood vessels. Since the implants were inserted into younger and younger patients, questions about their long-term biocompatibility and service life became more and more pressing. In 1976, a Medical Devices Amendment required manufacturers of implants to meet stricter standards—in some cases, standards still in the developmental stage.

James M. Cassel, chief of the Bureau's Dental and Medical Materials Section, headed an NBS program on synthetic implants at that time. Collaborating with Cassel were Freddy A. Khoury, Anna C. Fraker, John R. Ambrose, and Arthur W. Ruff; they studied the two largest areas of implant medicine, orthopedic and cardiovascular devices.

Orthopedic implants were made of stainless steel, cobalt-chromium alloys, or titanium alloys. Leading the way in such devices were artificial hips, with about 40,000 insertions per year. Fatigue and wear in use limited the service life of the

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[231] B. W. Mangum, "Mercury thermometers—are they becoming antiques?" *Dimensions/NBS*, February 1976, pp. 12-17.

prosthetic hips. Another factor in the service life of hip joint prostheses was the use of high-density polyethylene in the socket portion of the joint. It was subject to severe pressure because of its configuration and thus its wear characteristics were vital to the service life of the joint. And the cement used to hold the components of the implanted hip joint in place similarly was subject to extreme wear. Stephen S. Haas, Gerhard M. Brauer and George Dickson developed a polymethylmethacrylate bone cement that was effective with prosthetic implants.[232]

Energy Conservation

Research and other activities in support of energy conservation, created as a major thrust of NBS work during the tenure of Richard Roberts, continued as an active program under Director Ambler. Following are brief notes on some of these projects.

ETIP Initiates the Modular Integrated Utility System Study

Jordan Lewis, head of the Bureau's *Experimental Technology Incentives Program,* announced during 1976 the selection of the University of Florida, at Gainesville (UF), to test a new concept in energy generation and conservation that was given the name "Modular Integrated Utility System" (MIUS). The announcement was made jointly with Gerrit D. Freemouw of the Department of Health, Education, and Welfare, and Robert Q. Marston, President of UF.

The sub-systems comprising MIUS at UF included the generation of a fraction of needed power on the site of the project; the creation of a heating, ventilating, air conditioning, and hot water system; systems for disposal of liquid and solid waste; and the conservation of potable water.[233]

Clinton Phillips of the Office of Housing and Building Technology, Department of Housing and Urban Development was the lead technical advisor for the MIUS project. John Schaefgen was the leader of the MIUS demonstration project at the Bureau. One of the major goals, they stated, was the conservation of energy used within the demonstration community through recovery of waste heat, typically discarded into ponds or streams by electrical utilities. Other goals included protection of the environment, cost minimization, and maintaining high system reliability.

Besides the University of Florida project, a second contract was let for a project to be centered on the construction of a new town, St. Charles, Maryland, located 40 km southeast of Washington, DC. The town was planned to incorporate one high-rise apartment building, 205 apartments in four-story units, 200 townhouses, a shopping mall, offices, and a high school.

At the time of the award of the project, it was hoped that energy savings as large as 40 % could be realized by the new approach. A bonus would take the form of reduced environmental pollution.

[232] S. S. Haas, G. M. Brauer and G. Dickson, "A characterization of polymethylmethacrylate bone cement," *J. Bone J. Surg.* **57A**, No. 3, 380-391 (1975).

[233] "University of Florida, Gainesville, Selected to Test Integrated Utilities System Concepts," *Dimensions/NBS,* March 1976, p. 19.

The MIUS experiment provided a useful model for a national utility program rooted in energy conservation and environmental protection.

Energy-Efficient, Automatic Control of Furnaces

A new furnace-testing facility was completed in 1980 by the NBS Center for Mechanical Engineering and Process Technology. It was designed to improve the energy efficiency of industrial furnaces using automatic controls and heat-recovery systems known as "recuperators."

Recuperators, heat exchangers that recovered energy from hot exhaust gas to pre-heat the make-up air prior to combustion, lent complexity to automatic furnace controls, explained Hratch Semerjian, project leader for the new installation. The efficiency of the recuperator depended upon the temperature of the incoming air, which in turn depended upon the temperature of the recuperator. Developing the procedures for balancing the control system in the presence of such feedback mechanisms presented a problem which industrial combustion engineers were happy to bring to NBS.

The furnace was a slot-forging type rated at 300 kW (1 million Btu/h), with a maximum air preheat of 850 °C. A mini-computer was dedicated to the development of the control algorithm.

The furnace project also enabled Bureau scientists to study the combustion characteristics of various fuels and evaluate diagnostic test methods for furnaces.

Insulating an Older Home

NBS scientists showed the value of insulating homes against the heat and cold during 1978-79. Using the Bowman House, mentioned in Ch. 1, they measured the energy consumption of the poorly insulated home under simulated conditions of occupancy, then insulated it and installed storm windows. The energy consumption in the house dropped by nearly 60 %.[234]

Catching Energy Losses With Infrared Thermography

The value of infrared thermography for detecting loss of energy from residential and industrial structures was convincingly demonstrated in 1978 by scientists from the Center for Mechanical Engineering and Process Technology.

As part of the EPIC publications series, Lawrence A. Wood, John F. Ward, and Kenneth G. Kreider described a specialized camera that produced images indicating the temperature distribution on the outside surfaces of industrial furnaces—for example, an iron-forging furnace. The information would allow an exact calculation of the rate of loss of energy, a growing expense at that time.[235]

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[234] "National Bureau of Standards, A National Resource for Science and Technology, Fiscal Year 1978," *NBS Special Publication 538,* July 1979, p. 35.

[235] L. A. Wood, J. F. Ward, and K. G. Kreider, "Energy management for furnaces, kilns, and ovens," *Handbook 124,* January 1978, 44 pp.

Environmental Science

Many Bureau projects of this period influenced the welfare of man's environment. Of these, we highlight only a few: a sampling device for life deep in the ocean, ozone-layer chemistry, a study of smog, corrosion by the environment, and the polluting aspects of oil spills.

A Deep-Ocean Sampler Wins a Prize

Heat Division physicists Max Klein, Meyer Waxman, and Harry A. Davis made a brief excursion into the high-pressure world of deep-sea biotechnology during the late 1970s and came away with an award for their trouble.

Rita R. Colwell and Paul S. Tabor, microbiologists at the University of Maryland, needed help in retrieving live microorganisms from the ocean depths. Study of the living microbes was important to understanding their roles—if any—in decomposing wastes at great depths, and in the deep-ocean life cycle. They came to NBS for aid in designing a specialized sampling device primarily because Colwell was married to a Bureau physicist, Jack H. Colwell, of the NBS Heat Division, who was well aware of the Bureau's capabilities in high-pressure physics.

Davis, Waxman, and Klein designed a sampling apparatus for use to depths of 10,000 m, where the pressure was about 1000 times atmospheric pressure. The design proved entirely suitable for its tasks: to pre-pressurize a sterilized interior sampling chamber; to capture a sample at the required depth; to maintain the sample at its deep-water pressure while allowing the scientists to study enclosed microorganisms in the laboratory; and to permit the extraction of small samples at will.

The device was relatively small, inexpensive to construct, corrosion-resistant, safe, and reliable. Trials in the Puerto Rico Trench at 6800 meters depth brought up live bacteria of unknown types in addition to species previously studied with great effort. The device was immediately commissioned by the microbiology team for routine use.

The deep-ocean sampler was cited by Industrial Research and Development magazine as a winner of its 1979 IR-100 award, given to the "100 most significant new technical products."

Chlorofluorocarbons vs the Ozone Layer

The idea that chlorofluorocarbons, used extensively in refrigeration, air conditioning, and as propellants for bug bombs and paint, might absorb ultraviolet light, thereby freeing atomic chlorine to deplete the earth's protective ozone layer, led to a search for details of such a process.

The Bureau's Robert J. Celotta, Stanley R. Mielczarek, and Chris E. Kuyatt, members of the Optical Physics Division, collaborated with Russell H. Huebner and David L. Bushnell of the Argonne National Laboratory to establish a few relevant facts, using the technique of electron-loss spectroscopy.

In a laboratory at the University of Maryland (UM), Max Klein, an NBS physicist, and Rita R. Colwell, a UM microbiologist, looked at colonies of deep ocean micro-organisms cultured from water samples retrieved by the deep-ocean sampling device (on counter).

Key to the method was the ability to count electrons of a given energy. The team's spectrometer was designed so that electrons projected from a gun were made to pass through a monochromator that transmitted only those electrons moving within a narrowly defined range of energy. The transmitted beam then passed through the test gas where some fraction of the electrons lost energy by colliding with atoms or molecules of the test gas. From there, the electrons were accelerated and energy-analyzed before entering a detector. The group estimated that cross-sections for electron-molecule interaction could be determined by the device within about 15 %.

Two chlorofluorocarbons, $CFCl_3$ and CF_2Cl_2, were studied by the group. Their results agreed well with one of two sets of measurements that themselves differed by factors of two to four.[236] Because the NBS-Argonne experimental arrangement incorporated very different systematic errors than the other experiments, the results were seen as strong confirmation of data published by Mario Molina and Sherwood Rowland of the University of California at Irvine, who had proposed the ozone-breakdown theory.

More information came from Pierre J. Ausloos, Richard E. Rebbert, Michael J. Kurylo, and Walter Braun, all members of the Physical Chemistry Division.

[236] R. H. Huebner, D. L. Bushnell, R. J. Celotta, S. R. Mielczarek, and C. E. Kuyatt, "Ultraviolet photo-absorption by halocarbons 11 and 12 from electron impact measurements," *Nature* **257**, No. 5525, pp. 376-378 (1975).

University of Maryland microbiologist Paul S. Tabor guided the deep-ocean sampler from the deck of a research vessel.

Ausloos and Rebbert studied the photodecomposition of $CFCl_3$ and CF_2Cl_2 at several different wavelengths, using methane and ethane to intercept atomic chlorine. They derived values for the quantum yields of half a dozen molecular fragments resulting from the photodissociation. Near the lower limit for absorption, they found evidence that atomic chlorine was indeed released during the photodissociation process. At higher photon energies, it appeared that two chlorine atoms were produced from each reacting halocarbon molecule. [237]

Kurylo and Braun, meanwhile, simulated the effect of sunlight on the reaction of atomic chlorine with ozone, using the process of flash-photolysis resonance fluorescence. They obtained the rate constant for one of the sequential reactions that was predicted by Molina and Rowland to result in essentially catalytic conversion of ozone to ordinary oxygen in the presence of atomic chlorine and sunlight.[238]

NBS was well into the ozone-layer controversy.

A New Molecule, Born in Smog

An entirely new class of chemical compounds was identified during research at NBS on the components of smog. The new molecule, called dioxirane, was discovered in reactions between ozone and ethylene. Predicted by theorists on the basis of the energetics of reactions, the molecule had defied detection until two Bureau research teams found it independently.

Richard D. Suenram and Frank J. Lovas of the Optical Physics Division identified the three-membered ring compound, which contained only carbon, hydrogen, and oxygen, using the technique of microwave spectroscopy at low temperatures (77 K). The two physicists carried out the ozonolysis reaction in a waveguide held at the temperature of boiling nitrogen.[239] The new molecule appeared to consist of a small ring in which two oxygen atoms were singly bonded to each other and to a CH_2 radical.

Working independently, John T. Herron, Robert E. Huie, and Richard I. Martinez found the molecule, too. They observed dioxirane as a product of the low-temperature reaction of ozone with ethylene, using the methods of photoionization mass spectrometry in the gas phase. They found that the molecule decomposed to form hydrogen and carbon monoxide.[240]

The following year, Suenram and Lovas expanded their study to provide information on the synthesis, structure, microwave spectrum, and dipole moment of dioxirane. They were able to synthesize several isotopic forms of the molecule involving ^{12}C, ^{13}C, ^{16}O, and ^{18}O, obtaining molecular constants for the resulting isotopes.[241]

[237] R. E. Rebbert and P. J. Ausloos, "Photodecomposition of $CFCl_3$ and CF_2Cl_2," *J. Photochem.* **4**, pp. 419-434 (1975).

[238] M. J. Kurylo and W. Braun, "Flash photolysis resonance fluorescence study of the reaction $Cl+O_3=ClO+O_2$ over the temperature range 213-298 K," *Chem. Phys. Lett.* **37**, No. 2, 232-235 (1976).

[239] F. J. Lovas and R. D. Suenram, "Identification of dioxirane (H_2COO) in ozone-olefin reactions via microwave spectroscopy," *Chem. Phys. Lett.* **51**, No. 3, 453-456 (1977).

[240] R. I. Martinez, R. E. Huie, and J. T. Herron, "Mass spectrometric detection of dioxirane, H_2COO, and its decomposition products, H_2 and CO, from the reaction of ozone with ethylene," *Chem. Phys. Lett.* **51**, No. 3, 457-459 (1977).

[241] R. D. Suenram and F. J. Lovas, "Dioxirane, its synthesis, microwave spectrum, structure, and dipole moment," *J. Am. Chem. Soc.* **100**, 5117-5122 (1978).

Corrosion, an Expensive Problem

When Congress directed NBS "to embark upon a study of the economic effects of corrosion," they got their money's worth. By early 1978, the first phase of the study, covering the year 1975, was complete. A report, *Economic Effects of Metallic Corrosion in the United States,* provided details based upon a carefully chosen economic model. The model included all identifiable cost elements, along with an error analysis. It was considered to be the most reliable estimate of the economics of corrosion ever produced.

The report placed U.S. corrosion costs at the level of $70 billion each year. Some $10 billion, according to the study, could be avoided by the use of corrosion-control technology already in existence. Substantial savings of energy and of raw materials would also result if appropriate steps were taken to reduce the likelihood of corrosion.

Jerome Kruger, Lawrence H. Bennett, Robert L. Parker, Elio Passaglia, Curt Reimann, Arthur W. Ruff, and Harvey Yakowitz of NBS were joined in the project by Edward Berman of Edward B. Berman Associates to form the study team. Bennett pointed out that the $400,000 undertaking verified with solid information what many suspected. Corrosion was a tremendously costly problem to the Nation.

The study targeted for special attention three sectors of American activity; the electric power industry, the Federal government, and privately owned automobiles. About $4 billion was lost to the electric power industry through corrosion, including approximately 50 % of all maintenance costs for power generators. As much as 2 % of the Federal budget paid for corrosion costs—about $2 billion for maintenance and a staggering $6 billion in capital costs. Corrosion-based costs to the owners of private automobiles were not so firmly identifiable, but estimates ranged from $6 billion to $14 billion per year.[242]

Preparing for Oil Development in Alaska

Environmental dangers inherent in developing enormous oil reserves found near the Alaskan shore were obvious. As far back as 1971, sections of pipe were shipped to Prudhoe Bay, site of successful drilling on the northern coast of Alaska, to begin construction of a trans-Alaska pipeline all the way to Valdez, the southern pipeline terminus on Prince William Sound. Damage to the marine environment of both coasts could easily occur, along with degradation of the ecology of any state crossed by a line conveying as much as 2 million barrels per day of crude oil.

NBS became involved in the project during 1974 at the request of the National Oceanic and Atmospheric Administration (NOAA). Harry S. Hertz and Stuart Cram, chemists in the Bureau's Analytical Chemistry Division, and Herbert Bruce of NOAA led a team of investigators who were assigned the task of collecting baseline data on the marine environment of Alaska. The group was requested to pay particular attention

[242] L. H. Bennett, J. Kruger, R. L. Parker, E. Passaglia, C. Reimann, A. W. Ruff, H. Yakowitz, and E. Berman, "Economic Effects of Metallic Corrosion in the United States," *NBS Special Publication 511-1,* May 1978, 65 pp.

to existing levels of hydrocarbons. Stephen N. Chesler, Willie E. May, Stephen Wise, Dalmo P. Enagonio, Susan M. Dyszel, and Barry Gump, a visiting scientist from the California State University at Fresno, comprised the balance of the study group.

Because they were looking for extremely low levels of contaminants, the team sought especially sensitive collection and analytical techniques for the investigation. About 700 samples of sediment, water, and marine life were collected over a 2-year period. Flights in light aircraft, collection in whatever weather conditions prevailed, and extreme care to avoid contaminating the samples even as they were obtained, made the project challenging.

Back in the laboratory, the samples were immersed in specially purified water and the hydrocarbons removed by flowing nitrogen gas, to be analyzed later by the methods of gas chromatography, mass spectrometry, or liquid chromatography. The results, cross-checked in triplicate, were believed to be significant at the $\mu g/kg$ (parts-per-billion) level.[243]

The precautions taken by NOAA and NBS proved prophetic on March 24, 1989, when the *Exxon Valdez,* an oil tanker, struck a reef in Prince William Sound. The largest oil spill in U.S. history resulted; some 10 million gallons of oil were released, with enormous damage to the coastal environment.

Oil in the Monongahela

The collapse of a large oil tank on January 2, 1988, released nearly 1 million gallons of oil into the Monongahela River near Pittsburgh. The tank capacity was 4 million gallons. After nearly 40 years of service elsewhere, it had been re-installed at an Ashland Oil Company storage terminal. As the tank was filled for the first time in its new position, it ruptured.

An NBS team from the Structures Division, including John L. Gross, Felix Y. Yokel, Richard N. Wright, A. Hunter Fanney, John H. Smith, George E. Hicho, and T. Robert Shives, investigated the spill, identifying the cause of failure of the tank.[244] The Bureau work helped the American Petroleum Institute and the Environmental Protection Agency to reduce the probability of such failures in the future.

Non-Destructive Evaluation

Consumer safety, energy conservation, and industrial productivity were expected to benefit from a new NBS program known as non-destructive evaluation. Initiated as an inexpensive means for quality control in manufacturing, the technique became something of a self-contained specialty as a result of its broad application.

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[243] S. N. Chesler, B. H. Gump, H. S. Hertz, W. E. May, S. M. Dyszel, and D. P. Enagonio, "Trace hydrocarbon analysis: The National Bureau of Standards Prince William Sound/Northeastern Gulf of Alaska baseline study," *NBS Tech. Note 889,* 73 pp., January 1976.

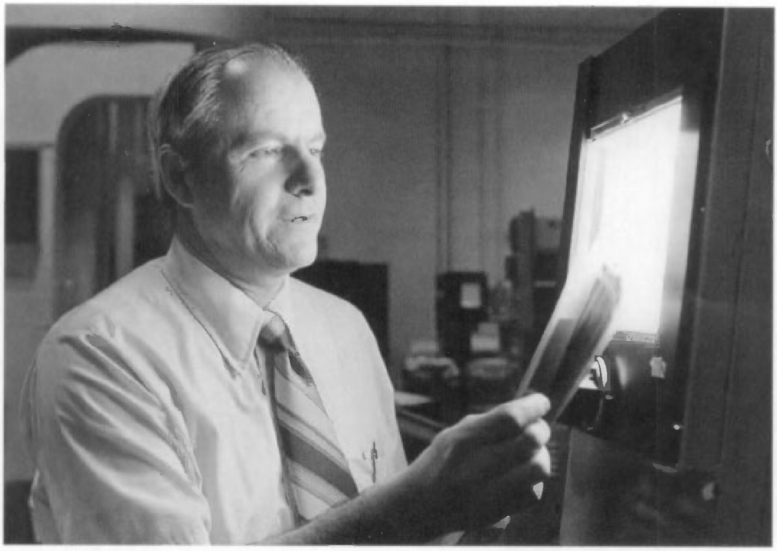
[244] J. L. Gross, F. Y. Yokel, R. N. Wright, A. H. Fanney, J. H. Smith, G. E. Hicho, and T. R. Shives, "Investigation into the Ashland Oil storage tank collapse on January 2, 1988," *NBSIR 88-3792*, June 1988, 202 pp.

Assisting in the Alaskan oil baseline study, NBS chemist Stuart P. Cram dug for samples of marine life in the early morning hours.

A variety of scientific methods found application as NDE techniques, according to Harry Berger, a physicist in the Reactor Radiation Division, who was selected to head the new program. These included ultrasonics, radiography, visual-optical, eddy-current, liquid penetrant, and magnetic particles. Each technique had the advantage that defects could be spotted without causing damage to the object under test; use of NDE methods to examine materials prior to manufacture could save considerable expense in processing costs. Most NDE methods could be used to find service-related failures in products or materials, saving repair costs or preventing failure-related accidents.

A symposium on NDE testing standards, co-sponsored by the Bureau, ASTM, and the American Society for Non-destructive Testing, was held at Gaithersburg on May 19-21, 1976.[245]

[245] H. Berger, "The National Bureau of Standards program in nondestructive evaluation," pp. 317-327 in *American Society for Testing and Materials Special Technical Publication 624, "Nondestructive Testing Standards*—A Review," H. Berger, editor, (Philadelphia: ASTM, June 1977).



Harold Berger inspected neutron radiographs as part of an NBS program to improve measurement methods used in the non-destructive evaluation of materials.

Berger himself offered one of many discussions of non-destructive methods—those used in nuclear science, his specialty.[246] He described gamma ray and neutron sources, as well as the techniques involved in non-destructive studies:

- Neutron and x-radiography.
- Scatter and secondary radiation, using x rays and neutrons.
- Activation analysis with neutrons.
- Radioactive tracers.

Testing Prosthetics With Vibration

Piezoelectric polymers, discussed at some length in the next section, made possible a variety of non-destructive tests on as many types of materials. In the hands of Darrell H. Reneker, Seymour Edelman, Aime S. DeReggi, and David L. Vanderhart, the devices permitted the non-destructive testing of plastic prosthetic materials prior to their implantation. Making use of the high mechanical compliance of the piezoelectric polymers, the group found they could perform vibrational spectroscopy to detect hidden manufacturing flaws in the materials. The method involved synchronization of a mechanical shock to the test material and the computerized recording of the oscillatory

[246] H. Berger, "Nondestructive evaluation: A review of nuclear methods," pp. 427-437 in *22nd International Instrumentation Symposium*, B. Washburn, editor, (Pittsburgh; Instrument Society of America, 1976).

return signal from the piezoelectric transducer. On-line analysis of the return signal to produce Fourier transforms revealed the frequencies and intensities of the normal modes of vibration of the test piece; flawed materials exhibited spectra different from those of perfect samples.[247]

Inspecting Objects With Neutrons

In a cooperative project with the U.S. Navy, the Reactor Research Division used the ability of neutrons to "see" through metal walls into the inner parts of Navy aircraft.

Using the method of neutron radiography, Donald A. Garrett was able to detect corrosion in the aluminum aircraft components with high sensitivity. Using specialized imaging techniques, Garrett found that he could provide visual evidence of the corroded parts on x-ray film. Quantification of the extent of the corrosion appeared possible.[248]

Garrett also was able to respond to a request for more accurate determination of levels of lubricating oil in a special jet engine. Early tests, using x rays, were not encouraging, but Garrett's use of thermal neutrons from the NBS high-flux reactor proved to be just the ticket. Oil levels were imaged by the neutrons using irradiation times as short as ten minutes.

Garrett produced many other images with the neutron radiograph technique as well, examining the quality of high-performance turbine blades, viewing activators for spacecraft solar panels for trouble spots, studying the interior of an ancient Chinese urn, and diagnosing the chemical activity of batteries in use.

X-Ray Magnifier

X-ray images of industrial equipment often provided evidence of cracks, voids, or other imperfections. Frequently, however, it was desirable to magnify the image for more detailed examination. Ordinary photographic enlargement techniques could offer the needed enlargement with satisfactory resolution, but the technique was slow and cumbersome. A method was wanted that offered real-time analytical convenience.

Masao Kuriyama, William J. Boettinger, and Harold E. Burdette provided a solution to the problem—an x-ray magnifier built on the principle of successive diffractions of the x-ray beam from carefully prepared silicon crystals. Their device magnified the test image before it reached the detector.[249]

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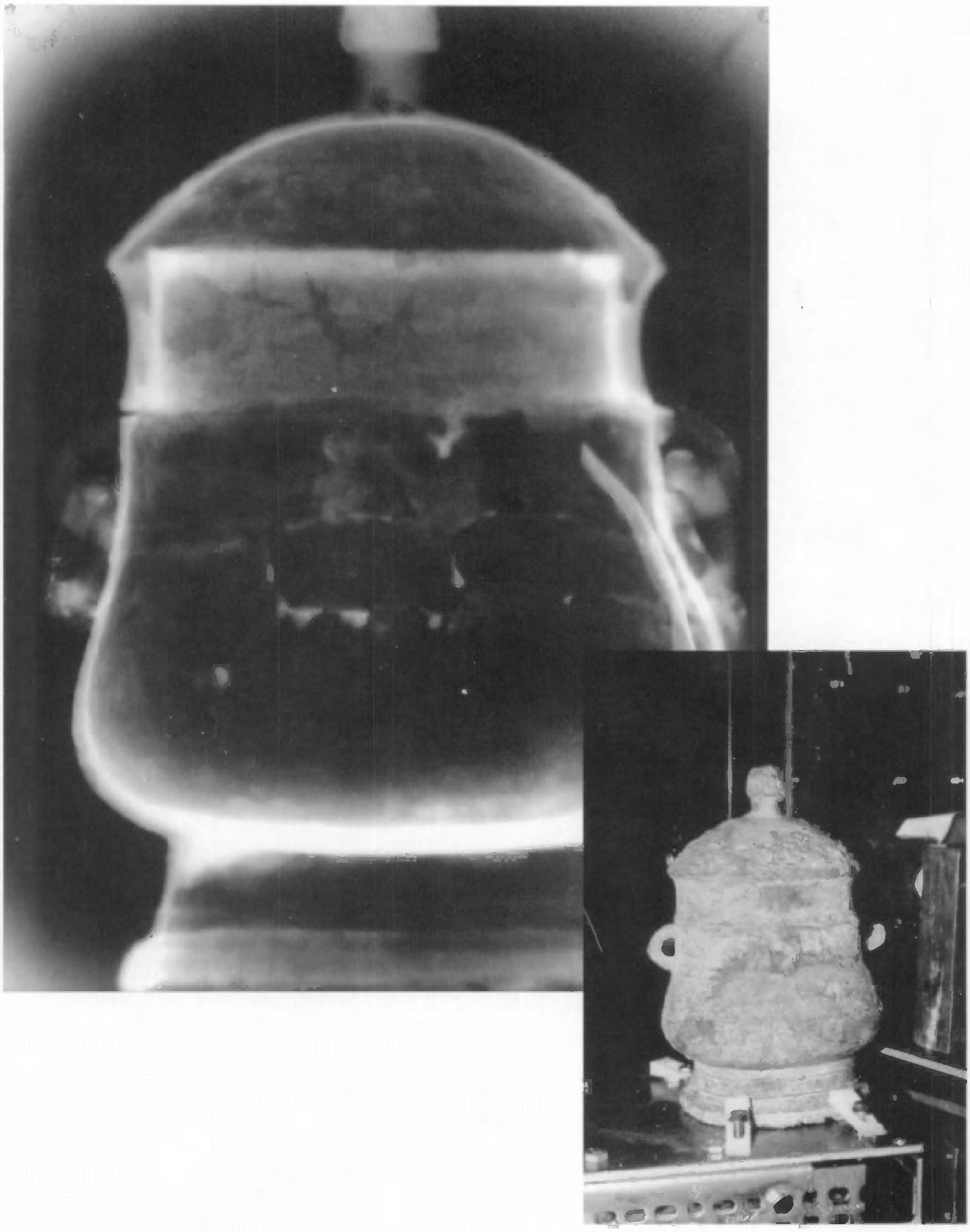
[247] D. H. Reneker, S. Edelman, A. S. DeReggi, and D. L. Vanderhart, "An ndt method using piezoelectric polymer transducers and computerized vibrational spectroscopy" *NDT Intl.*, pp. 15-16 (February 1978).

[248] D. A. Garrett, "The macroscopic detection of corrosion in aluminum aircraft structures with thermal neutron beams and film imaging methods," *NBSIR 78-1434,* December 1977, 42 pp.

[249] W. J. Boettinger, H. E. Burdette, and M. Kuriyama, "X-ray magnifier," *Rev. Sci. Instrum.* **50**, No. 1, 26-30 (1979).



In 1977, NBS researchers demonstrated a way to use neutron radiation in xeroradiography. In a successful application of this new tool for non-destructive evaluation, Bureau scientists analyzed a sealed ancient Chinese lead vessel for the Smithsonian Institution. Neutron radiograph from the collections of the Freer Gallery, Smithsonian Institution. Reprinted courtesy of the Hermitage Foundation Museum, Norfolk, Virginia. The inset shows the vessel waiting to be irradiated.

NBS Metallurgy Division scientist Masao Kuriyama with the x-ray magnifier that he developed. It won Industrial Research and Development magazine's IR-100 award in 1979.

The x-ray magnifier developed by Kuriyama's group improved the resolution of industrial x-ray imaging by a factor of 25, and furthermore could be used as the part was examined.

Gentle Tests for Bipolar Transistors

Semiconductor switches called bipolar power transistors were used to power high-voltage and high-current devices, including such items as automobile ignition systems. Testing the transistors was a chancy enterprise, because of the risk of damage to the units owing to variability in their manufacture. As a result, untested units occasionally failed during use, to the chagrin of the new owner.

Researchers from the Center for Electronics and Electrical Engineering developed a non-destructive test circuit for the bipolar power transistors. The circuit placed a variety of electrical conditions on the transistors while monitoring the voltages in key locations. Any potentially damaging readings caused removal of the power within about 40 ns, before destruction of the device could occur. Use of the test circuit during manufacture gradually decreased the in-service failure rate of the transistors.

Polymer Science

Studies in polymer science generally include theoretical studies, crystal and structure observations, properties information, and applications. Each of these is represented in the following accounts.

Crystal Growth in Polymers

Fundamental studies in the nucleation and growth of polymers involved a number of scientists in the Polymer Science Division, as well as colleagues elsewhere.

Janice Breedon Jones and P. H. Geil, a visitor from Case Western Reserve University, experimented with the cracking of polyoxymethylene (POM) single crystals grown on Mylar film. Stretching of the Mylar film stressed the POM crystals to the point of rupture. Jones and Geil examined the areas containing the resulting cracks to gain insight into the mechanisms of deformation in polymeric substances. By the use of electron microscopy, they obtained detailed images of the broken surfaces. In one case they found indications that a very thin surface film might exist, and that it might be so lightly attached that it would slip under the stress of deformation.[250]

John D. Hoffman and G. Thomas Davis presented a model representing the surface of folded-chain polymer single crystals. They hoped to explain the experimental indications of the occasional existence of surface layers that exhibited different properties from the bulk of polymer crystals. Such "amorphous" layers, if present, could account for results such as those reported by Jones and Geil.[251]

[250] Janice Breedon Jones and P. H. Geil, "Surface films on poly(oxymethylene) single crystals," *J. Res. NBS* **79A**, No. 5, 609-611 (1975).

[251] John D. Hoffman and G. Thomas Davis, "On the origin of the amorphous component in polymer single crystals and the nature of the fold surface," *J. Res. NBS* **79A**, No. 5, 613-617 (1975).

In a long discussion, Hoffman, John I. Lauritzen, Jr., Lois J. Frolen, and Gaylon Ross described the rates of growth of polyethylene crystals. They used the formalism of nucleation constants and observed the crystal growth in terms of the magnitude of undercooling and the molecular weight of particular samples, which spanned the range 3600 to more than 800,000. Particular stress was laid on the influence on crystal growth of the number of surface sites and on the morphology of the resulting crystals.[252]

Frolen and Ross each had served NBS for nearly 25 years by 1975; the two nearly always worked as a team. Ross, formerly a chemist in the U.S. Navy, joined the Bureau's Pure Substances Section in 1951. Frolen first came to the attention of the Bureau as a Westinghouse Science Talent Search winner at about the same time. Thereafter she became a summer-time student employee, assisting Harold F. Stimson in studies of benzoic acid and then joining Ross in the Pure Substances Section; in 1955, she became a full-time Bureau employee. In 1964, the two were transferred to the Polymers Division, where they continued their productive collaboration.

Polymers—Sensors for Heat and Pressure

Because of research accomplished at NBS, certain polymers joined single-crystal solids in providing useful electromechanical devices based upon the principle of piezoelectricity. Polymeric piezoelectrics brought advantages in flexibility, low density, toughness, size versatility, and low cost that were lacking in the generally brittle and relatively dense inorganic materials.[253]

The phenomenon of pyroelectricity generally accompanied piezoelectricity in polymers. The co-existence of the two properties presented problems if measurement times allowed the test sample to change temperature during piezoelectric measurements.

A number of Bureau projects featured the use of polymeric piezoelectrics and pyroelectrics, most undertaken by scientists in the Polymers Division, including Martin Broadhurst, Seymour Edelman, G. Thomas Davis, John McKinney, Steven Roth, Fred Mopsik, R. E. Collins, Aime DeReggi, and James Kenney.

One of the devices used in the program was used to monitor heart rates. The similarity of the polymer to human tissue permitted easy application to skin.

Another project involved the testing of piezoelectric polymers as pressure sensors for the U.S. Treasury Department, for use in presses that printed paper money.

Other uses of the devices include detonators, hydrophones for underwater sonar, underground tunneling sensors, and temperature detectors for radiometric instruments.[254]

[252] John D. Hoffman, Lois J. Frolen, Gaylon S. Ross, and John I. Lauritzen, Jr., "On the growth rate of spherulites and axialites from the melt in polyethylene fractions: Regime I and regime II crystallization," *J. Res. NBS* **79A**, No. 6, 671-699 (1975).

[253] S. Edelman, "Piezoelectric and pyroelectric polymer sensors," *Proc. Conf. on Sensor Technology for Battlefield and Physical Security Applications, Fort Belvoir, VA, July 13-15, 1977*, pp. 204-212.

[254] Detailed discussions of piezoelectric polymers can be found in *Dimensions/NBS*, February 1978, pp. 3-9; and *NBS Standard*, March 8, 1978, pp. 4-5.

NBS was sought out by manufacturers and other government agencies for assistance in the use of piezoelectric polymers because it was one of the few laboratories that supported its experimental work with continuing theoretical and analytical studies.[255]

Davis and Broadhurst, for example, developed a theoretical treatment for piezoelectricity and pyroelectricity in polymer electrets; it was based upon a model of molecular dipoles, aligned during the poling procedure and frozen thereafter. Their theory was able to account for experimental results on polyvinylchloride, a glassy polymer.[256]

Spectroscopy involving x ray, infrared, and Raman techniques were commonly used for analysis of the polymeric sensor materials.

Durability of High-Density Plastics

During the early 1980s, John M. Crissman and Freddy A. Khoury began testing the durability of ultra-high-molecular-weight polyethylene. These polymers, with molecular weights as high as 4 million, were used in applications requiring exceptional durability and wear characteristics. Medical prosthetics was one of the most demanding of these applications; the lifetime of medical implants was determined, in the main, by the durability of the materials from which the implants were prepared. Creep, wear, and fatigue in use were the principal causes of failure. In turn, these mechanisms were related to crystallinity, orientation, size of spherulites, molecular weight, and molecular weight distribution.

By 1982, studies of the methods of preparation of the raw polymer powders, establishment of procedures for forming bulk and sheet materials, and elementary characterization of the formed materials were behind the two scientists. Work then focused on measurements of the morphology, density, viscosity, stress-relaxation, and fatigue of the highest-molecular-weight polyethylene. Its density ranged from 0.923 g/cm^3 for sheets quenched from the melt to 0.942 g/cm^3 for slowly annealed sheets.

As a check on the variability with molecular weight of the critical properties of this class of polymer, Crissman and Khoury prepared and tested sheets with molecular weight only half as large (2 million). The densities were only slightly different.

Both types of polyethylene retained memory of the granular texture of the raw polymer after forming, and both showed good recovery from strains less than those needed to break the materials.

Studies of the properties of the ultra-high-molecular-weight polyethylene polymers continued for some time. They served in a variety of applications that extended well beyond medical implants.

[255] One such study was performed by M. G. Broadhurst, G. T. Davis, S. C. Roth, and R. E. Collins, "Pyroelectricity and charge transport in a copolymer of vinylidene fluoride and tetrafluoroethylene," *Proc. Conf. Electrical Insulation and Dielectric Phenomena, Buck Hill Falls, PA, Oct. 18-21, 1976*, pp. 38-47.

[256] G. T. Davis and M. G. Broadhurst, "Piezoelectricity and pyroelectricity in polar polymers," *Proc. Intl. Symp. on Electrets and Dielectrics, Sao Carlos, Brazil, Sept. 1-6, 1975*, pp. 299-319.

Thermodynamic Properties of Macromolecules

In 1983, Umesh Gaur, Suk-fai Lau, Brent B. Wunderlich, and Bernhard Winderlich, prepared the seventh, eighth, and ninth installments to complete a series of articles on the thermodynamic properties of linear macromolecules. The scientists, members of the Chemistry Department of the Renssalaer Polytechnic Institute, were finishing a project initiated several years previously in collaboration with the NBS Office of Standard Reference Data.

The series was published in the *Journal of Physical and Chemical Reference Data.*[257] A joint publication of the American Chemical Society and the American Physical Society for NBS founded in 1972, the publication provided an outlet for information that was critically reviewed by experts in the many topics treated in its pages. The strength of the Journal papers was the reliability of the information—mainly data, as implied by its name—contained therein. The first editor was David R. Lide; he was followed by Jean W. Gallagher in 1993 and Malcolm W. Chase in 1996.

With the completion of the series, the colleagues of the Polymers Division scientists had tabulated heat capacity data, enthalpies, entropies, melting and other transition temperatures, and a variety of other thermodynamic information for a large group of polymers. Much of the data originated with Bureau work, and the OSRD support made it available in coherent form for a wide audience.

Measuring Tiny "Space Beads"

A measurement problem came to the Bureau from outer space during 1983, as the U.S. space shuttle "Challenger" landed. On board was a packet of several billion polystyrene beads, formed into nearly identical spheres about 10 μm in diameter during Challenger's flight.

The odyssey of the little beads began in a contract between personnel of Marshall Space Flight Center and the Emulsion Polymers Institute of Lehigh University. Lehigh Professor John W. Vanderhoff headed a small group who developed a novel technique for producing beads of approximately the desired size and shape, but found that—on earth—gravity caused the beads to take non-spherical shapes and to vary substantially in size. The National Aeronautics and Space Administration (NASA) was happy to design an apparatus to duplicate bead preparation in space, since NASA would acquire another payload item if the production experiment turned out to be a success. Already in the NASA records were successful production of two sets of smaller beads.

[257] Several papers written by U. Gaur, S. Lau, B. B. Wunderlich, and B. Winderlich appeared in the *Journal of Physical and Chemical Reference Data* **12**, No. 1, (1983):

Gaur, Wunderlich, and Wunderlich, "Heat capacity and other thermodynamic properties of linear macromolecules. VII. Other carbon backbone polymers," pp. 29-63.

Gaur, Lau, Wunderlich, and Wunderlich, "Heat capacity and other thermodynamic properties of linear macromolecules. VIII. Polyesters and polyamides," pp. 65-89.

Gaur, Lau and B. Wunderlich, "Heat capacity and other thermodynamic properties of linear macromolecules. IX. Final group of aromatic and inorganic polymers," pp. 91-108.

Two NASA engineers, Johnny M. Oddo and Jack E. Churchey, built the bead-producing equipment. Challenger astronauts and mission specialists operated the equipment during the April 1983 flight. Then came the "acid test:" deliver the beads to NBS for observation and measurement.

Investigation of the polystyrene beads was placed in the hands of Thomas R. Lettieri of the Mechanical Production Metrology Division by Lee J. Kieffer and Stanley D. Rasberry of the Office of Standard Reference Materials. With Arie W. Hartman, Gary G. Hembree, and Egon Mark, Lettieri found that the beads made in the weightless environment of space were extremely uniform in size and nearly spherical in shape.

The group had several different measurement methods at their disposal to study the beads. Using an optical microscope to view the beads under illumination from a collimated light source, Hartman was able to use a technique called "center distance finding." It utilized the light-refracting property of the tiny spheres to produce points of light; the distance separating two points could yield an average bead diameter. This method resulted in a value of 9.89 μm with a variance of only 0.04 μm.[258]

The new SRM, first space-produced beads to be offered for sale, was given the identification SRM 1960. Hembree, Lettieri, Kieffer, and Hartman shared a 1986 IR-100 award, given by *Research and Development* magazine for new technical products judged most significant.

Eventually, the list of polystyrene beads offered in the SRM program also included sizes of 30 μm (SRM 1961), 1 μm (SRM 1690) and 0.3 μm.

Physical Science

In this section, we see surface studies, phase relationships, television captioning, gravimetry, aerosol physics, nuclear safeguards, cooled atoms, and cold-neutron research.

Surface Physics

Theodore E. Madey, newly granted the Ph. D. degree in physics from the University of Notre Dame, and John T. Yates, with a fresh Ph. D. degree in chemistry from MIT, both arrived at NBS in 1963 as postdoctoral research associates. Within a year, they learned that they shared an interest in the science of surfaces. Soon they were trying to produce metal surfaces that were really clean and free of adsorbed atoms of any kind, let alone the grease and grime that covered the ordinary surface.

The studies of atomically clean metal surfaces by Madey and Yates led naturally to an interest in catalysis. In a 1977 report, they offered results that showed a high level of catalytic activity for an atomically clean tungsten surface, synthesizing methane

[258] Gail Porter, "New particles for measuring pigments, flour, blood cells," *NBS Research Reports*, October 1984, pp. 16-19.

molecules from hydrogen and carbon monoxide. This work, countering previous negative results for the same type of experiment, demonstrated the value of completely removing adsorbed material from catalytic surfaces.[259]

An effective method of looking closely as adsorbed gases were blasted from metal surfaces was developed by the two scientists. It was an apparatus that performed a procedure they called ESDIAD. ESDIAD offered a new way of looking at surfaces. It was the acronym for *Electron Stimulated Desorption Ion Angular Distributions,* a mouthful that referred to the phenomenon that occurred when an electron beam struck a metallic single crystal covered by adsorbed gas. In one example, oxygen and hydrogen gas atoms were emitted as positive ions from an otherwise clean (100) surface of tungsten. The angular distribution of the ions depended upon the positions which the oxygen and hydrogen atoms occupied with respect to the metal crystal atoms. The ions were detected with an image intensifier and displayed on a fluorescent screen. In other experiments, they were able to identify the way that water molecules bonded to single-crystal ruthenium surfaces.[260]

A National Academy of Sciences panel identified surface science as one of the most fruitful types of study in materials science. Madey and Yates, both staff members of the Physical Chemistry Division, helped make it so. The two scientists received the NBS Samuel W. Stratton Award in 1978 for their work in surface catalysis.

Many Bureau theoretical contributions to surface physics came from J. William Gadzuk, a solid-state theorist trained at MIT. He created models for the processes involved in spectroscopic measurements at surfaces, in the dynamic response to external perturbations of many-body systems, and in the dynamics of atomic and molecular reactions.

Gadzuk joined NBS in 1968 and immediately began to collaborate with E. Ward Plummer and Russell D. Young on electron tunneling to metal surfaces (see Ch. 3 Section on the Topografiner). His grasp of theoretical ideas helped make the group unusually productive in the physics of tunneling into clean metallic surfaces and through adsorbed atoms and molecules.[261] One brief paper, entitled "Resonance tunneling of field emitted electrons through adsorbates on metal surfaces,"[262] was the first report in which the electronic energy levels of atoms adsorbed on metal surfaces were observed experimentally and interpreted theoretically. By itself, it provided guidance

[259] R. D. Kelley, T. E. Madey, and J. T. Yates, Jr., "Activity of tungsten as a methanation catalyst," *J. Catal.* **50**, 301-305 (1977).

[260] T. E. Madey and J. T. Yates, Jr., "Evidence for the conformation of H_2O adsorbed on Ru(001)," *Chem. Phys. Lett.* **51**, No. 1, 77-83 (1977).

[261] See, for example, J. W. Gadzuk, "Resonance-tunneling spectroscopy of atoms adsorbed on metal surfaces: theory," *Phys. Rev.* **B1**, No. 5, 2110-2129 (1970); E. W. Plummer and J. W. Gadzuk, "Surface states on tungsten," *Phys. Rev. Lett.* **25**, No. 21, 1493-1495 (1970); J. W. Gadzuk and E. W. Plummer, "Hot-hole—electron cascades in field emission from metals," *Phys. Rev. Lett.* **26**, No. 2, 92-95 (1971).

[262] E. W. Plummer, J. W. Gadzuk, and R. D. Young, "Resonance tunneling of field emitted electrons through adsorbates on metal surfaces," *Solid State Comm.* **7**, 487-491 (1969).

for later work on electron-energy-level spectroscopy of adsorbed species. A collaboration between Gadzuk and Plummer produced a lengthy review of the physics underlying the measurement of the energy distribution of field-emitted electrons.[263]

Gadzuk's theoretical studies at NBS/NIST continued apace for three decades, reaching into the areas of angle-resolved photoemission spectroscopy, core-level and vibrational spectroscopy, dynamics and chaos in surface processes, surface interactions at sub-picosecond time intervals (femtochemistry), and solid state tunneling.

Numerous honors came to Gadzuk for the quality and quantity of his work at NBS. He received the Arthur S. Flemming Award as one of the ten outstanding Federal employees of 1978. The award was given for Gadzuk's theoretical work on surface physics. Also in 1978, Gadzuk was awarded a guest professorship by the Nordic Institute of Theoretical Atomic Physics in Copenhagen. Gadzuk took advantage of the grant mainly for study at the Institute for Theoretical Physics in the Chalmers University in Sweden. The award provided for visits to the institute for two to three weeks at a time, several times each year.

A "Renaissance" Scientist Comes to NBS

During 1977, John W. Cahn joined the NBS Center for Materials Science. A veteran of service as theorist to the General Electric Company and as professor of materials science at MIT, Cahn quickly became known at NBS for the depth and diversity of his knowledge of materials.

Already well-known for his work on the thermodynamic limits to phase stability, Cahn soon published discussions of interphase boundaries near the critical point of two-phase fluids[264] and antiphase boundary motion in alloys.[265]

By 1980, Cahn was heavily involved in materials research with NBS colleagues, including Michael R. Moldover, William J. Boettinger, Samuel R. Coriell, Gretchen L. Kalonji, and Frank S. Biancaniello.[266] One of these projects was a study of rapid solidification phenomena. By dropping the temperature of molten materials at rates of 10^4 K/s or greater, scientists could produce microstructures of unusual compositional uniformity and high levels of supersaturation; in addition, metastable phases could be

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[263] J. W. Gadzuk and E. W. Plummer, "Field emission energy distribution (FEED)," *Revs. Mod. Phys.* **45**, No. 3, 487-548 (1973).

[264] J. W. Cahn, "Critical point wetting," *J. Chem. Phys.* **66**, 3667-3672 (1977).

[265] S. M. Allen and J. W. Cahn, "A microscopic theory for antiphase boundary motion and its application to antiphase domain coarsening," *Acta Metallurgica* **27**, 1085-1095 (1979).

[266] M. R. Moldover and J. W. Cahn, "An interface phase transition: complete to partial wetting," *Science* **207**, 1073 (1980). J. W. Cahn, W. J. Boettinger, and S. R. Coriell, "Rapid solidification," paper in *Laser and Electron Beam Processing of Materials,* C. W. White and P. S. Peercy, editors, (New York: Academic Press, 1980), p. 89. W. J. Boettinger, F. S. Biancaniello, G. M. Kalonji, and J. W. Cahn, "Eutectic Solidification and the formation of metallic glasses," *Proc. Second Intnl. Conf. on Rapid Solidification Processing: Principles and Technologies,* R. Mehrabian, B. H. Kear, and M. Cohen, editors (Baton Rouge: Claitor's Publishing Division, 1980), p. 50.

obtained, yielding materials with unexpected properties. In some cases, such as diamond, the natural conversion to the stable, equilibrium state (in the case of diamond, graphite) occurred at an immeasurably slow pace.[267]

A paper written in 1984 with colleagues from Israel and France attracted unusual attention even for Cahn, who, by that time, possessed honors and awards from many parts of the globe for his scientific research. The new communication described a startling discovery; "quasicrystals," a metastable phase with icosahedral symmetry but the sharp x-ray diffraction patterns characteristic of crystals.[268] One of the characteristics of icosahedral symmetry was its inconsistency with lattice "translations." The new materials were formed by the rapid solidification of alloys containing 10 atomic percent to 14 atomic percent of manganese, iron, or chromium in aluminum. The publication sparked a furor in crystallography and the study of metastable materials.

Among the many awards earned by Cahn during his service to NBS were the Department of Commerce Gold Medal in 1984 and the NBS Stratton Award in 1986. In 1998, he was awarded the National Medal of Science by President William J. Clinton; it was the nation's highest scientific honor.

An "Emmy" For NBS

"Emmy" awards, given for outstanding contributions to television by the Academy of Television Arts and Sciences, did not usually go to NBS—in fact, the Bureau never had received the prize until 1980. However, Dicky Davis accepted an Emmy on September 6, 1980. It was jointly awarded to NBS, to the Public Broadcasting Service, and to the American Broadcasting Company for the development of closed captioning for the deaf.

Closed captions were broadcast along with regular programs, but decoded only with the use of specialized equipment. Viewers with hearing defects could use the decoders to "see" the dialog accompanying the program.

The closed-caption technique originated with a system called TvTime, developed by Davis, James Jesperson, and George Kamas in 1971 as a means of disseminating time and frequency information to a large audience.[269] NBS collaborated with ABC to broaden the concept to include program dialog, and prepared decoding devices for the use of PBS. During 1979, three major networks, ABC, NBC, and PBS initiated regular broadcasts of captioned programs.

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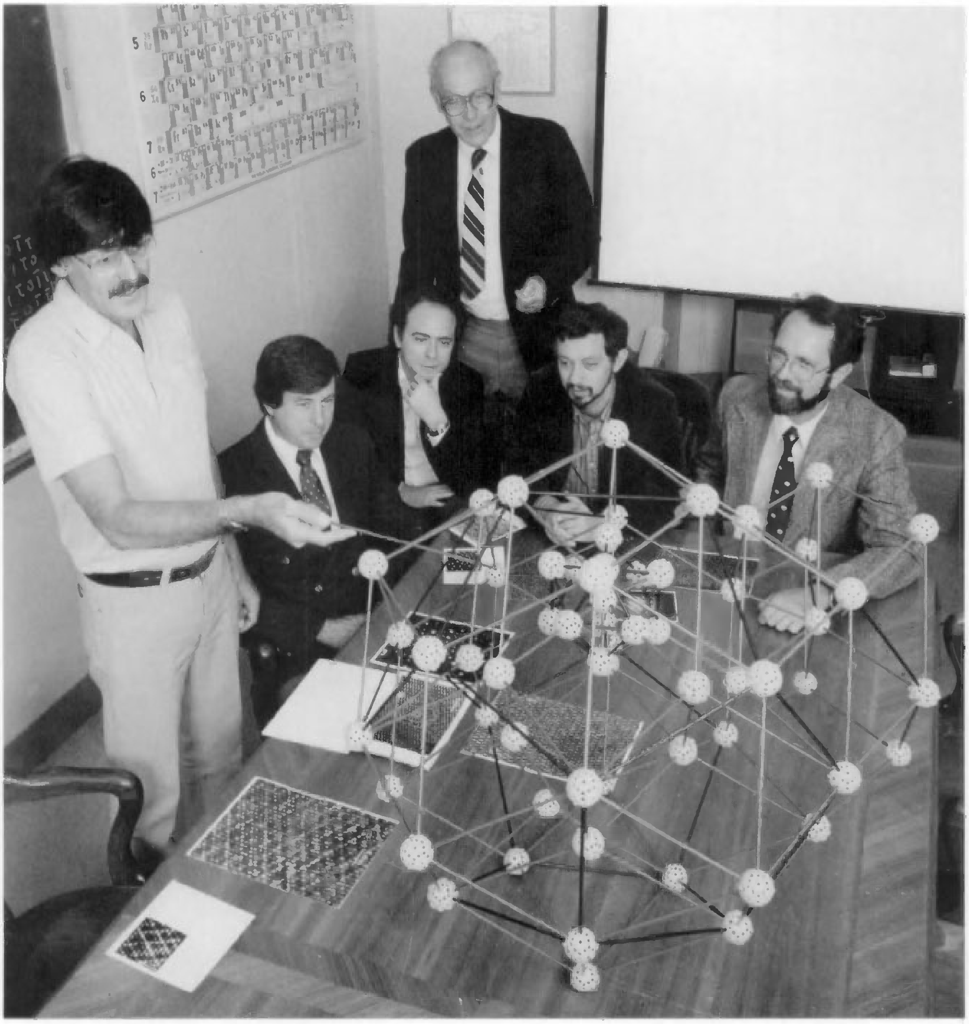
[267] See for example John W. Cahn and Denis Gratias, "Quasi-periodic crystals: a revolution in crystallography," chapter in *Advancing Materials Research*, Peter A. Psaras and H. Dale Langford, editors, (Washington, DC: National Academy Press, 1987) p. 157.

[268] D. Shechtman, I. Blech, D. Gratias, and J. W. Cahn, "Metallic phase with long-range orientational order and no translational symmetry," *Phys. Rev. Lett.* **53**, 1951-1953 (1984).

[269] See Ch. 2 for a brief description of the process. Details also are given in *NBS Standard* **25**, No. 19, p. 1.



A team of NIST scientists and visiting researchers led by John W. Cahn discussed quasicrystal structures in alloys. From left to right were Dan Shechtman of the Israel Institute of Technology, Frank S. Biancaniello of NIST, Denis Gratias of the National Science Research Center in France, John W. Cahn of NIST, Leonid A. Bendersky of Johns Hopkins University, and Robert J. Schaefer of NIST.

A Super Spring for a Super Gravimeter

The isolation of experiments sensitive to very slight mechanical disturbances was a problem from the beginning of science. The use of heavy tables, for example for optical spectroscopy and laser work, reduced the response to all but building and earth vibrations. The addition of mechanical or pneumatic springs to a massive support further isolated sensitive equipment from all vibrations of frequency higher than the natural resonance frequency of the mass-spring system. But there the problem lay until James E. Faller and Robert L. Rinker of JILA took it up in the mid-1970s.

Faller and Rinker, eventually accompanied by a succession of colleagues including William A. Koldewyn, wished to measure the rise and fall of the earth's surface with a portable device in order to better understand the science of tectonics. The desire included a price. They needed an absolute means of measuring the acceleration due to gravity, previously measured at NBS by others, including Paul R. Heyl.[270] They devised an instrument—a gravimeter—based upon the notion of free-fall of a mass. It contained a drag-free, free-fall chamber; a stabilized laser; and suitable timing electronics. The trouble was that, in order to effectively isolate the instrument from the earth's natural microseismic vibrations using the mass-plus-spring technique, a spring about 1 kilometer in length would be necessary.

Faller and Rinker tackled the problem by designing a servo system to move the upper support for a 30 cm spring closely in rhythm with the experiment dangling from the spring. In this fashion the effective length of the support spring could be forced to respond as if it were as long as tens of kilometers!

By 1982 the gravimeter had been completed and tested. Results indicated its measurement uncertainty to be no more than 6 parts in 10^9, providing an equivalent height sensitivity of about 2 cm.[271] Faller and two of his colleagues spent some time making measurements in California, New Mexico, Colorado, Wyoming, Maryland, and Massachusetts. The measurement accuracy indicated by the results: about 3 cm.[272]

Identifying Molecular Impurities

During 1977, Edgar S. Etz and Gregory J. Rosasco reported the development of a new analytical tool, a laser-excited Raman microprobe that could be used to identify a variety of impurities, even those present only in tiny (micro-meter) particles.

Significant in use of the new microprobe for the identification of chemical species was a discovery by the two spectroscopists in collaboration with Wayne A. Cassatt[273] that the spectra produced by very small particles were analytically identical to those from macroscopic particles of the same composition. This discovery made it possible for them to use the Raman technique for fine aerosols, often necessary for air-pollution studies.

[270] P. R. Heyl, "A redetermination of the constant of gravitation," *J. Res. NBS* **5**, 1243 (1930).

[271] J. E. Faller, Y. G. Guo, and M. A. Zumberge, "Determination of absolute gravity," *Proc. Amer. Soc. of Photogrammetry, Amer. Cong. on Surveying and Mapping, Denver, Co*, Mar. 14-20. 1982, pp. 63-74.

[272] M. A. Zumberge, J. E. Faller, and J. Geschwind, "Results from an absolute gravity survey in the United States," *J. Geophys. Res.* **88**, No. B9, 7495-7502 (1983).

[273] G. J. Rosasco, E. S. Etz, and W. A. Cassatt, *Appl. Spectrosc.* **29**, 396 (1975).

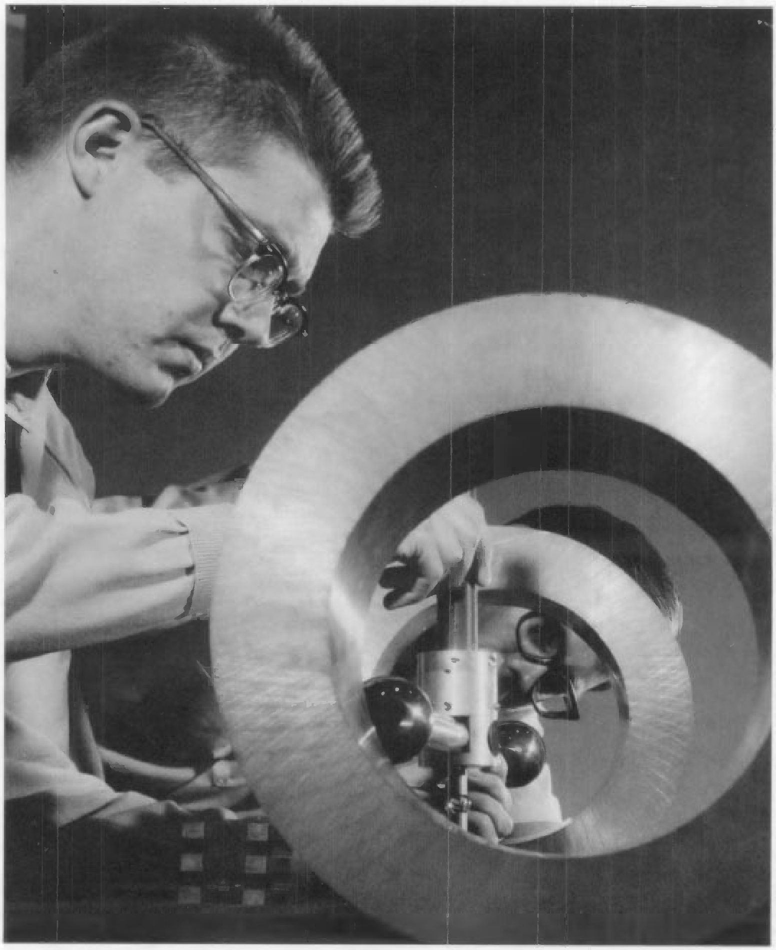
In 1930 and again in 1942, NBS physicist Paul R. Heyl redetermined the Newtonian constant of gravitation.

The Raman microprobe used an argon-krypton ion laser to irradiate the test samples in a carefully prepared irradiation chamber. A mechanism composed of a differential micrometer and a piezoelectric translator was employed to move the sample substrate in order to focus the irradiating beam on the chosen particle. A double monochromator provided the Raman-scattering spectrum for detection by a photomultiplier tube.[274]

Rosasco and Etz were able to balance inherent experimental conflicts: between maximizing beam power and minimizing sample damage from the beam; and between supporting the test sample in a rigid manner and avoiding intense background radiation from the substrate. The pair chose sapphire as the substrate material, taking advantage of its relatively weak Raman activity.

The versatility of the Raman microprobe was demonstrated by the observation of particles of thorium oxide, ammonium sulfate, "urban dust" (identified through its spectrum as calcium sulfate), cholesterol, and polyvinyl chloride. The new instrument became a potent tool for analytical chemists.

[274] G. J. Rosasco and E. S. Etz, "The Raman microprobe: a new analytical tool," *Research/Development* 28, (June issue) pp. 20-35 (1977).

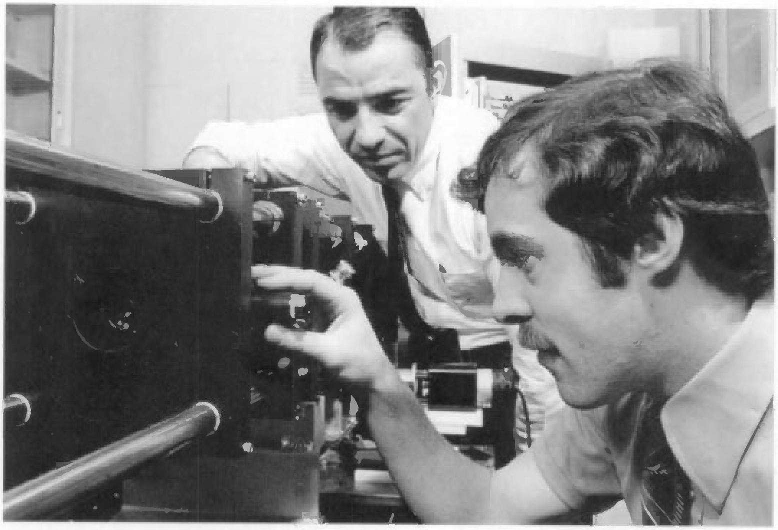


In 1977, James E. Faller (right) and William A. Koldewyn of the Joint Institute for Laboratory Astrophysics conducted an experiment to measure the acceleration due to gravitation even more precisely than Heyl did.

Measurements for Nuclear Materials

Late in 1979, the NBS Office of Measurements for Nuclear Technology and the Institute of Nuclear Materials Management co-sponsored a conference on measurements for nuclear safeguards and control of nuclear materials. The 4-day meeting featured more than 60 papers on measurement methods, inventory techniques, assay of reactor materials, and management systems designed to keep nuclear materials safely. The proceedings were edited by T. R. Canada and by B. Stephen Carpenter of the NBS Reactor Radiation Division.[275]

[275] "Measurement technology for safeguards and materials control," T. R. Canada and B. S. Carpenter, editors, *NBS Special Publication 582*, 769 pp., June 1980.



Edgar S. Etz watched as Gregory J. Rosasco adjusted the eyepiece of a laser-excited Raman spectrometer that the two scientists developed to identify the composition of tiny particles.

Among the topics discussed during the conference by Bureau authors were the following:

- Role of NBS Standard Reference Materials in measurement accuracy, by William P. Reed.
- Mass-spectrometric determination of the half-life of ^{241}Pu, by Ernest L. Garner and Lawrence A. Machlan.
- Resonance neutron radiography measurements for safeguards, by Roald A. Schrack, James W. Behrens, Charles D. Bowman, and Allan D. Carlson.
- Reactor track-etch power monitor, by B. Stephen Carpenter, Ivan G. Schroder, Lawrence J. Pilione, J. W. Roe, and S. Santani.
- In situ density of solutions, by Frank E. Jones, Randall M. Schoonover, and John F. Houser.

Sharper Lines from Cooler Atoms

By the early 1980s one of the principal impediments to improved resolution in high-precision spectroscopy and to improved frequency standards was the fuzziness of spectral lines incurred because of the thermal motion of the participating atoms. The Doppler effect—the increase or decrease of observed line frequency caused by motion of the atom towards or away from the observer—was an inevitable consequence of the temperature of the experimental species.

Two groups of NBS scientists attempted to minimize the Doppler effect by trapping ions or atoms in ingenious "cages" and reducing their velocities—and thus their temperatures—by various means.

An ion-storage group, working in the NBS/Boulder laboratories, numbered among its collaborators Robert E. Drullinger, Fred L. Walls, John J. Bollinger, Wayne M. Itano, Joseph S. Wells, James C. Bergquist, H. Hemmati, and R. G. Hulet. Leader of the group was David J. Wineland, a Harvard-trained physicist who joined NBS in 1975. One of the first successes of Wineland's group was the cooling of doubly ionized magnesium ions below 40 K during 1978. The ions were confined in an electromagnetic Penning trap, then irradiated with a dye laser tuned for resonant photon capture to slow their motion. Theirs was the first such observation.[276]

Wineland's group made spectacular progress during the next several years in their efforts to create a new frequency standard based on laser-cooled ions. By 1991, they had demonstrated a frequency standard using cooled beryllium ions, with a level of reproducibility comparable to that achievable with NBS-6, the then-current national frequency standard (8 parts in 10^{14}).[277]

Finding that mercury ions were less susceptible to certain types of frequency shift than beryllium ions, the Boulder group explored a new area. They were able to cool mercury ions to the point where they existed 99 % of the time in the $n = 1/2$ state, creating a quantized-harmonic-oscillator system. This advance allowed resulted in a new frequency standard at 40 GHz with a reproducibility of one part in 10^{16}—superior to that of NIST-7, the present national frequency standard.[278]

Joining NBS in 1978 was William D. Phillips, recently awarded the Ph. D degree in physics by MIT. Despite the spartan atmosphere at NBS dictated by presidential economies, Phillips was hired for his great promise in the fields of fundamental constants, atomic physics, and electrical standards.[279]

By 1983, Phillips and Harold Metcalf, a visiting scientist from the University of New York at Stony Brook, had assembled in Gaithersburg an experiment that demonstrated the use of counter-propagating resonant laser beams to decelerate neutral sodium atoms to about 40 % of their thermal velocities. A 500 °C oven produced a continuous collimated beam of sodium atoms directed along a decreasing magnetic

[276] D. J. Wineland, R. E. Drullinger, and F. L. Walls, "Radiation-pressure cooling of bound resonant absorbers," *Phys. Rev. Lett.* **40**, No. 25, 1639-1642 (1978).

[277] J. C. Bollinger, D. J. Heinzen, W. M. Itano, S. L. Gilbert, and D. J. Wineland, "A 303 MHz frequency standard based on trapped beryllium ions," *IEEE Trans.* **IM-40**, pp. 126-128 (1991).

[278] D. J. Berkeland, J. D. Miller, J. C. Bergquist, W. M. Itano, and D. J. Wineland, "A laser-cooled mercury ion frequency standard," *Phys. Rev. Lett.* **80**, pp. 2089-2092 (1998).

[279] Barry N. Taylor, Memo to Emanuel Horowitz, Deputy Director, National Measurement Laboratory, May 15, 1978. Subject; "Dr. William Phillips: Target of Opportunity." Taylor noted that Phillips, an outstanding young scientist, had an interest in NBS and enthusiasm for imaginative and careful measurements.

field. The changing Zeeman effect on the atomic levels of the sodium atoms tended to bunch atoms of like velocity-distribution as they met the oncoming laser beam. Despite some tricky problems with optical pumping of the atoms by the laser beam, deceleration was clearly demonstrated.[280] Within months, Phillips, John V. Prodan, and Metcalf had reduced the equivalent temperature of a neutral sodium beam to about 70 mK, only 4 % of its initial velocity.

In April 1983, a 2-day workshop was held at the NBS Gaithersburg laboratory on slow atomic beams. Some 20 participants presented papers on the methods and applications of cooled atoms. Both Wineland and his group and Phillips and his co-workers exhibited their latest results.[281]

The laser-cooling work continued with greater and greater success. By 1985, the Gaithersburg group learned how to build a magnetic trap to confine the neutral atoms for about a second so that measurements of their properties could be performed.[282] By 1988, the level of cooling reached 40 μK, far below the equivalent temperature limit supposed possible in then-current theories.

For participating in the development of experiments that opened a new field of study, Wineland, Bergquist, Bollinger, and Itano received the Department of Commerce Gold Medal in 1985. The same group shared the 1989 Stratton Award. In 1990, Wineland received the Davisson-Germer Prize of the American Physical Society and the William F. Meggers Award of the Optical Society of America. He was elected a member of the National Academy of Sciences in 1992.

For his part in leading the way to the use of lasers to cool and trap atoms, Phillips—by then a NIST fellow—was elected to the National Academy of Science in April 1997. Later that year, Phillips and two of his colleagues, Steven Chu of Stanford University and Claude Cohen-Tannoudji of the Ecole Normale Superieure of Paris, shared the 1997 Nobel Prize in physics. It was the first Nobel Prize for an NBS/NIST employee.

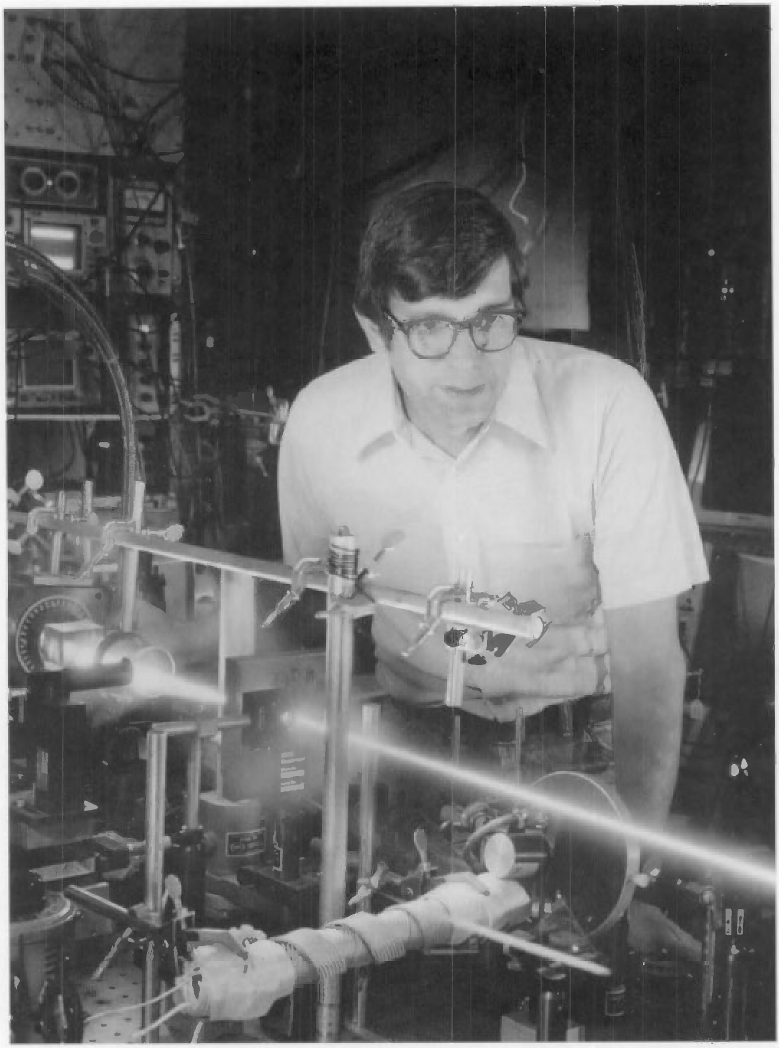
Cold Neutrons for Science

On January 12, 1989, a *Cold Neutron Research Facility* was dedicated at NIST. It was the first such facility in America dedicated entirely to research. Before the new NIST facility opened, Bureau scientists performed cold-neutron experiments

[280] William D. Phillips and Harold Metcalf, "Laser deceleration of an atomic beam," *Phys. Rev. Lett.* **48**, No. 9, 596-599 (1982).

[281] "Laser-cooled and trapped atoms," *NBS Special Publication 653*, W. D. Phillips, editor, June 1983, 172 pp. Papers included the following: pp. 1-8, W. D. Phillips, J. V. Prodan, and H. Metcalf, "Neutral atomic beam cooling experiments at NBS"; pp. 19-26, D. J. Wineland, W. M. Itano, J. C. Bergquist, J. J. Bollinger, and H. Hemmati, "Frequency standard research using stored ions"; pp. 137-141, J. V. Prodan and W. D. Phillips, "Chirping the light—fantastic? Recent NBS atom cooling experiments"; and pp. 142-153, R. Blatt, W. Ertmer, and J. L. Hall, "Cooling of an atomic beam with frequency-sweep techniques."

[282] A. L. Migdall, J. V. Prodan, W. D. Phillips, T. H. Bergeman, and H. J. Metcalf, "First observation of magnetically trapped neutral atoms," *Phys. Rev. Lett.* **54**, No. 24, 2596-2599 (1985).



NBS/NIST atomic physicist and Nobel Prize winner William D. Phillips with his laser cooling and trapping apparatus circa 1988.

wherever they could.[283] Cold neutrons, produced by a block of D_2O ice held in the temperature range 30 K to 40 K by re-circulating helium gas, served some 15 experimental stations in the NIST research reactor by the time the installation was

[283] See, for example, R. M. Lindstrom, R. Zeisler, and M. Rossbach, "Activation analysis opportunities using cold neutron beams," *J. Radioanalytical and Nuclear Chem.* **112**, No. 2, 321-330 (1987).

fully completed in 1993.[284] The new facility incorporated a *Small Angle Neutron Scattering* capability, a depth profiling instrument, prompt-gamma-ray activation analysis, and a variety of other instrumentation designed to take advantage of the greatly reduced thermal energy of the cold-neutron beam. J. Michael Rowe was designated as the NIST contact for the new facility.

New Radius for the Carbon Nucleus

A group of radiation physicists including Lawrence S. Cardman, John W. Lightbody, Jr., Samuel Penner, Sherman P. Fivozinsky, and Xavier K. Maruyama of NBS and their colleagues W. P. Trower of Virginia Polytechnic Institute and S. E. Williamson of the University of Illinois used the Bureau linear electron accelerator to measure the elastic electron scattering cross-section from ^{12}C atoms. Analysis of the new data along with the results of an earlier experiment involving lower momentum transfer allowed them to determine the shape of the ground-state charge distribution and the charge radius with substantially improved accuracy. The new value of the charge radius of the carbon nucleus was determined with an uncertainty estimated at 0.6 %.[285]

New Classifications for Critical Data

Writing in the journal *Science* during 1981, David R. Lide, Jr., chief of the NBS Office of Standard Reference Data (OSRD), called attention to the avalanche of scientific data that by then was overwhelming the technical literature and suggested that there was a way to ease the increasingly tedious search for needed information.[286]

The solution to the scientific "information explosion," in Lide's view, was the omnipresent computer, itself source of much of the information flow. The development of computer-based bibliographic files that could be searched from remote terminals greatly increased access to documents for multitudes of researchers and technical workers. A second stage in bringing information directly to its users, Lide suggested, might be the provision of actual data on demand.

Providing data directly to those who needed the information carried certain risks, however. In many cases, the quality of the data was as important to the user as the actual numbers involved—and quality control in the production of scientific data was non-uniform at best.

Lide noted that even a vocabulary for information concepts was lacking in many areas—for example, the word "data" was used both to refer to documents and to numerical files of values.

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[284] A. Arif, R. D. Deslattes, M. S. Dewey, G. L. Greene, and I. G. Schroder, "Facilities for fundamental physics research at the NIST Cold Neutron Facility," *Nuclear Instruments and Methods in Physics Research* **A284**, 216-219 (1989).

[285] L. S. Cardman, J. W. Lightbody, Jr., S. Penner, S. P. Fivozinsky, X. K. Maruyama, W. P. Trower, and S. E. Williamson, "The charge distribution of ^{12}C," *Phys. Lett.* **91B**, No. 2, 203-206 (1980).

[286] David R. Lide, Jr. , Critical data for critical needs," *Science* **212**, June 19, 1981, pp. 1343-1349.

The classification of scientific data was addressed by the International Council of Scientific Unions as early as 1975. Through its Committee on data for Science and Technology, the Council provided a detailed scheme that recognized three broad classes of data:

- Repeatable measurements on well-defined systems. These data constituted much of the traditional output of experiments in physics and chemistry laboratories.
- Observational data, in which any values quoted depended on transient conditions that, in general, prevented checking by remeasurement.
- Statistical data on such subjects as demographics, materials production, health, and energy use.

Each of the classes of data were necessary for particular individuals in the pursuit of their goals, noted Lide, although the efforts of the OSRD lay principally in improving the quality of the information contained in the first-named class.

Lide reviewed computer-based methods still under development to improve the dissemination of information—methods that finessed the increasingly large costs of printing handbooks and journals. These included electronic data bases on interactive computer networks, use of magnetic tapes and other computer-compatible storage media, and on-line data-retrieval services.

Optical Fibers and the Information Age

What properties should optical fibers possess, and why would anyone particularly want optical fibers? As this history was written, the question sounded silly, given the intense effort today to stretch optical fibers around the world to speed communications. In the mid 1970s, however, few people understood the potential impact of optical fiber communications on telephone networks. Still fewer imagined the Internet, or other magic now worked by computer links.

It seems surprising, therefore, that the first significant proposal for telecommunications over fiber networks was published as long ago as 1966. And that two key advances—the reduction of attenuation of radiation below 20 dB/km in fibers, and the development of cw semiconductor lasers capable of room-temperature operation—occurred in 1970.

Fortunately for NBS, Harold S. Boyne, then chief of the Electromagnetics Division in Boulder, had friends in the telecommunications industry who helped him understand the potential benefits of optical communications:

- Far greater carrying capacity for information than copper wire.
- Better signal-to-noise properties than copper wire.
- Longer distances between repeater stations than copper wire.
- Effectively free of interference.

In the fall of 1975, Boyne took a member of his staff to the First European Conference on Optical Communications, held in London. There they heard researchers from the British Telecom Research Laboratories and elsewhere advocate the immediate deployment of optical fibers in the telephone networks, though only laboratory experiments had been conducted at that time.

A year later, Boyne called Douglas Franzen, Bruce Danielson, and Gordon Day to his office. Boyne told the trio to begin work on optical fibers.

> "What kind of work should we do?" they asked.
> "That's for you to find out," Boyne replied.
> Thus began NBS work on optical communications.

It soon became apparent to the three scientists that one could buy similarly-specified fiber from two different manufacturers and receive two very different products. The attenuation of an optical fiber produced in that era was in the range of several dB/km (two decades later, the best value was about 0.2 dB/km). The group showed by interlaboratory comparisons that the uncertainty of measurements among the various manufacturers was at best ± 1 dB. They demonstrated in the laboratory that it was possible to make more accurate measurements and they worked with standards groups, especially the Electronics Industry Association and the Telecommunications Industry Association, to help them develop standard measurement procedures.

There were similar problems to be solved for bandwidth measurements and many other fiber parameters. By 1980, the group had doubled in size, adding Robert Gallawa, George Chamberlain, and Matt Young.

In 1980, Franzen and Day initiated a biennial *Symposium on Optical Fiber Measurements*. It still provides a principal forum for reporting the results of research on optical fiber characterization.

The pattern of organizing interlaboratory comparisons to quantify measurement problems, working in the laboratory to understand measurement techniques, and collaborating with standards groups to develop standard procedures became a familiar one. As more instrumentation became available commercially, the work shifted toward the development of artifact standards—Standard Reference Materials—to serve as calibration references for the commercial devices.

The effectiveness of the NBS/NIST group was recognized by a large group of colleagues. The President of the Telecommunications Industry Association wrote, "Without the NIST assistance and leadership, the U.S. fiber optics industry would not be in the competitive position it enjoys today." The Department of Commerce, too, recognized the high quality of the group's effort with Bronze, Silver, and Gold Medal Awards.

Electronics and Electrical Engineering

Examples of contributions in the areas of electronics and electrical engineering include a new automated test facility, methods for flaw detection in integrated circuit manufacture, solar-cell materials, the evaluation of an interesting new device, and the measurement of contact resistance.

Automated Test Facility for A/D Converters

During this period, the static transfer characteristics of high-performance converters for analog-to-digital and digital-to-analog signals were evaluated automatically by a new test set developed by T. Michael Souders and Donald R. Flach. The new facility provided measurements of gain, offset, linearity, and equivalent input noise with an uncertainty not exceeding 4 ppm. Up to 40 readings per second could be performed without degrading the instrumental accuracy. The two scientists used a 20-bit digital-to-analog converter as a comparison standard.[287]

Quick Checks of Integrated Circuits

One problem that bedeviled manufacturers of integrated circuits during the late 1970s and early 1980s was circuit failure brought on by defects in manufacture. Tiny flaws in the semiconductor materials could result in equally small leakage currents, impairing the performance of the circuit. But these flaws were difficult to spot without extensive—and therefore, expensive—testing.

Center for Electronics and Electrical Engineering researchers Gary Carver and Martin G. Buehler attacked the problem by devising an integrated gated-diode electrometer that could be included in the manufacture of each semiconductor wafer. A tiny amplifier in the electrometer magnified any leakage currents and indicators of certain other quality defects, allowing the manufacturer to monitor the wafer by computer during processing. Wafers showing any indication of defects could be removed from the system. The electrometer also was used to monitor the fabrication and performance of charge-coupled detectors.[288]

Physicist David E. Sawyer and engineer David W. Berning of the Electronic Technology Division developed an instrument to test semiconductor devices. Called a "Flying Spot Scanner," the instrument could be used to map dc and high-frequency gains in transistors, reveal areas where non-linearities occurred, and detect the presence of "hot spots," all these in a non-destructive manner.[289]

The new apparatus was chosen for an IR-100 award in 1976.

Solar Cell Workshop

Eighteen papers were presented at a 1979 workshop co-sponsored by the Bureau and by the Department of Energy on the stability of thin-film solar cells. Data pertained to all the major materials used in the cells. The papers discussed subjects ranging over the economics of solar cells, the reliability of various cells, materials problems, and measurement problems.

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[287] T. M. Souders and D. R. Flach, "An automated test set for high resolution analog-to-digital and digital-to-analog converters," *IEEE Trans. Instrum. Meas.* **28**, No. 4, 239-244 (1979).

[288] G. P. Carver and M. G. Buehler, "The development of test structures for characterization of the fabrication and performance of radiation-hardened CCD imagers," *NBSIR 79-1744*, May 1979, 54 pp.

[289] For a synopsis of the scanner, see *Dimensions/NBS*, November 1976, pp. 17-18.

David W. Berning (left), an electronics engineer, and David E. Sawyer, a physicist, of the NBS Electronic Technology Division, operated the laser flying-spot scanner they developed for testing semiconductor devices.

The workshop proceedings were published in the *NBS Special Publication 400* series entitled "Semiconductor measurement technology" and edited by David E. Sawyer and Harry A. Schafft.[290]

Evaluating an "Energy-Producing" Device

One of the "hot potatoes" that arrived on the doorstep of the Center for Electronics and Electrical Engineering (CEEE) during the tenure of Ernest Ambler concerned the never-ending search for free power. One Joseph Newman had proffered a device which he claimed produced more power than it used. Neither the NBS Office of Energy-Related Inventions nor the U.S. Patent Office gave the device a second glance, since very basic laws of physics denied Mr. Newman even the possibility of success.

Mr. Newman held the opinion that his device should get a fair test, and said so in U.S. District Court. The judge in the case ruled that Mr. Newman had been denied due process, and he ordered that a technical review of the device be conducted forthwith. Patent Office officials negotiated with NBS officials, and responsibility for conducting the technical review fell upon Robert E. Hebner of the NBS Electrosystems Division of the Center for Electronics and Electrical Engineering.

[290] "Semiconductor measurement technology: NBS/DOE workshop, stability of (thin film) solar cells and materials," D. E. Sawyer and H. A. Schafft, editors, *NBS Special Publication 400-58*, August 1979, 181 pp.

For about 6 months during 1986, the Newman device resided at NBS. It was kept in a locked compartment throughout the examination except when it was actually under test. The District Court had ordered the production of a formal report on the test, with clear identification of the testing personnel and their credentials, full descriptions of the device, the NBS test equipment and procedures, and test results. More than one Bureau employee remembered the AD-X2 battery case and hoped for an early and satisfactory completion for the task.

The actual testing, done by Hebner, Gerard N. Stenbakken, and David L. Hillhouse, took some ingenuity. The machine contained a large coil of wire, a rotating permanent magnet, and a commutator that periodically reversed the connections from a battery-pack power supply. Its output consisted of a series of high-voltage pulses, so that some care was required to evaluate the output power.

Despite the problems, testing was completed with a few months. The testing team found that, once again, the laws of physics had triumphed over human ambition—the output power was less than the power used to run the machine.

The court-ordered report was carefully prepared, with a Foreword signed by Director Ambler, who stated:[291]

> Our results are clear and unequivocal. As the report states, "At all conditions tested, the input power exceeded the output power. That is, the device did not deliver more energy than it used."

Not a happy man, but at last the beneficiary of due process, Mr. Newman departed the scene. All the NBS participants in the case breathed sighs of relief and returned to more mundane matters.

Measuring Contact Resistance

Stephen J. Proctor and Loren W. Linholm, researchers in the Electron Devices Division, developed a test method for the measurement of contact resistance in metal-semiconductor contacts. They employed a two-dimensional resistor network model to relate the specific contact resistance to the measured interfacial contact resistance with a homogeneous interfacial layer. The authors illustrated the technique with measurements of aluminum contacts on n-type silicon and of contacts with a 98.5 % aluminum, 1.5 % silicon composition, also on n-type silicon.[292]

Computer Science

High Speed for the NBS Net

The NBS Net received a boost in the speed of its data communication with new equipment developed by Robert J. Carpenter, Joseph Sokol, Jr. and Robert A. Rosenthal. The three scientists noted the need for improvement in the development of

[291] Robert E. Hebner, Gerard N. Stenbakken, and David L. Hillhouse, "Report of tests on Joseph Newman's device," *NBSIR 86-3405,* June 1986, 35 pp.

[292] S. J. Proctor and L. W. Linholm, "A direct measurement of interfacial contact resistance," *IEEE Electron Device Lett.* **EDL-3**, No. 10, 294-296 (1982).

local-area computer networks. Their innovation involved a new terminal design which allowed a wide variety of terminals, microprocessors, and larger mainframes to be fully interconnected by a common coaxial cable. The so-called *Terminal Interface Equipment* was partitioned to permit modular expansion and data encryption.[293]

Aid for Computer-Aided Design

Computer-aided design became a popular tool during this period as smaller, dedicated computers appeared on the desks of the Nation's engineers. Plans for all sorts of projects, usually involving complex graphics programs used to design and portray new products on computer monitors, were speeded considerably by the use of "canned" data and procedures. One flaw in the CAD system, however, was a lack of digital transportability of the results to an installation manufactured by a different producer. In general, it was necessary for the operator to print out the results of the work and re-enter data in an unrelated CAD system.

The data transport problem was attacked by personnel from a consortium of industrial and government organizations, including Bradford M. Smith and Joan D. Wellington of the Bureau's Center for Manufacturing Engineering. Smith served as chair of the interface task group that represented the armed services, NASA, and more than forty large U.S. corporations. The group was successful in producing a mechanism that could solve the problem.

Completed in 1980 was a project called *Initial Graphics Exchange Specification* (IGES). The IGES enabled data originating on any CAD system to be transferred to any other CAD system, regardless of manufacturer. In addition, IGES provided an important link to Computer Aided Manufacturing systems, to robotic operations, and to other computer-assisted manufacturing activities.[294]

The task group noted that the IGES was not a panacea but a prototype. It was intended to alleviate then-existing data-exchange problems, which it did. But the concept embodied in IGES could be extended to other interface problems as the need arose.

When the improvement brought by the IGES became known, the American National Standards Institute, an organization supported by all areas of the Nation's technology sector, immediately commenced study of IGES as part of its program on industrial voluntary standards.

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[293] R. J. Carpenter, J. Sokol. Jr. , and R. A. Rosenthal, "A microprocessor-based local network node," *IEEE Catalog No. 78CH 1388-8C* (New York: IEEE, 1978) pp. 104-110.

[294] "A technical briefing on the Initial Graphics Exchange Program (IGES)," J. C. Kelly (Sandia Laboratories, Co-Chair), Robert Wolf (Xerox Corp., Co-Chair), Philip Kennicott (General Electric), Roger N. Nagel (International Harvester), and Joan D. Wellington (NBS Center for Manufacturing Engineering, editor), *NBSIR 81- 2297,* July 1981, 128 pp.

Evaluating Computer Performance

During 1983, the 19th meeting of the Computer Performance Evaluation Users Group was held in San Francisco. The 4-day meeting touched on a variety of problems associated with the utilization of supercomputers, microcomputers, and in-between sizes as well. Some of the topics were the following:[295]

- Local Area Networks—control of the flow of messages to buffered receivers, modelling a LAN.
- Statistical methods for computer evaluation.
- Improvement of software by modification and replacement methods.
- Sizing computer systems for particular applications.
- The Information Center concept for users of small systems.
- Automatic data processing—independent use *vs* organizational control.

Information Processing Standards

During Ambler's term as director, the Institute for Computer Sciences and Technology continued as the source of *Federal Information Processing Standards,* intended to guide government employees in the use of computerized data processing. New FIPS publications of the era addressed the following problems:

- Passwords (FIPS publication 112), which specified basic security criteria for verification of personal identity and for access to restricted data.
- Graphical Kernel System (publication 120), which noted the adoption as a FIPS of an American National Standards Institute (ANSI) protocol of computer subroutines for handling two-dimensional graphics packages.
- Syntax for handling videotex and teletex information (publication 121), which described the formats, rules, and procedures for encoding alphanumeric text and pictorial materials in those applications.
- Data Descriptive Files (publication 123), which noted the adoption as a FIPS of an ANSI specification for information exchange between computer systems without loss of data integrity.
- Revision of *FIPS* on *FORTRAN* (publication 69-1), which updated a standard issued earlier to specify the form and interpretation of programs written in the FORTRAN language.

During 1987-88, two new FIPS were issued that built on the effectiveness of the *Initial Graphics Exchange Specification,* mentioned earlier in this section. Known by the acronyms POSIX and GOSIP, they provided additional means for the interconnection of computer hardware and software, regardless of manufacturer.

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[295] D. Mowbray, editor, "Computer science and technology: Proceedings of the Computer Performance Evaluation Users Group, 19th meeting, October 25-28, 1983," *NBS SP 500-104,* October 1983, 236 pp.

POSIX, the *Portable Operating System Interface for Computer Environment* (publication 151), offered a standard for the transport of software from computer to computer. GOSIP, the *Government Open System Interface Profile* (publication 146-1), updated an international standard for data communications. The new standards encouraged computer vendors to offer products with enhanced versatility.

NBS Radiometry Comes of Age

In chapter 3 we noted progress in optical radiation measurements. More can be added to that story at this point, covering advances made during the latter half of the 1970s and the 1980s.[296]

Electrical Substitution Radiometry

The measurement of total radiant energy emitted by a variety of sources—for example, by lasers, by standard lamps, and by simulators of solar radiation—was eased considerably at NBS by the development of electrical substitution radiometry and by the development of electrically calibrated pyroelectric radiometers.

E. Dale West, a calorimetrist transplanted from the Gaithersburg Heat Division to the Boulder Quantum Electronics Division, joined colleagues W. E. Case, A. L. Rasmussen, and L. B. Schmidt to create an electrical substitution radiometer—basically a reference calorimeter—to evaluate the energetics of Boulder's new lasers. Use of the calorimeter allowed laser energy and power to be evaluated in terms of standard joules and watts, respectively.[297]

The operating characteristics of lasers made certain portions of the group's task particularly interesting. One such property was that of time variation in laser energy. Pulsed lasers delivered energy in short bursts; treated carefully, the pulsed outputs could be compared with those of continuous-wave lasers through calorimetry. In addition, transient variation in cw laser power could be averaged calorimetrically. West's group utilized the constant-temperature calorimetry method to develop a type of instrument designated the C-series calorimeter. The calorimeter accuracy was estimated as 1 % of the laser energy, with a range of 0.01 J to 20 J and with a limiting laser pulse intensity of 0.1 J/cm^2.

In the meantime, Jon Geist and Albert Crigler were working in the Heat Division on the measurement of incoherent radiant sources. They developed a versatile radiometer that could be used with lasers, standard lamps, and solar simulators.[298]

[296] Most of this material comes from an account kindly furnished by Jon Geist.

[297] E. D. West, W. E. Case, A. L. Rasmussen, and L. B. Schmidt, "A reference calorimeter for laser energy measurements," *J. Res. NBS* **76A**, No. 1, 13-26 (1972).

[298] J. Geist, "Fundamental principles of absolute radiometry and philosophy of this NBS program," *NBS Technical Note 594-1,* June 1972, 59 pp.

A comparison of the Boulder and Gaithersburg radiometers in 1973 produced agreement within 0.1 % in laser energy measurements, well within estimated uncertainties for the two devices.[299]

Use of the Geist-Crigler radiometer in a 1970 comparison of pyrheliometers—solar simulators—under the auspices of the World Meteorological Organization (WMO) of the United Nations demonstrated unexpectedly large errors in the international solar simulator calibrations. By 1979, however, the WMO, using the NBS information, was able to redefine its solar scale in terms of units consistent with the International System of Units.

Defoe C. Ginnings and Martin L. Reilly created a radiometer based upon the use of an electrical substitution calorimeter cooled to the temperature of liquid helium. The device was intended for measuring the temperatures of blackbody radiators,[300] and its advanced design provided a new level of accuracy in radiometric measurements. The principles developed by Ginnings and Reilly were subsequently incorporated by Terence J. Quinn and John E. Martin of the British National Physical Laboratory into a larger radiometer of extremely high accuracy.

Electrically Calibrated Radiometers

The development of electrically calibrated pyroelectric radiometers, like their substitutional cousins, took place both in the Boulder laboratories and the Gaithersburg laboratories. Robert J. Phelan, Jr., A. R. Cook, Clark A. Hamilton, and Gordon W. Day produced at Boulder an electrically calibrated pyroelectric radiometer.[301] Jon Geist, William Blevin, a guest worker from the Australian National Measurement Laboratory, and Albert Crigler accomplished a similar development at Gaithersburg.[302]

The two efforts produced instruments that were more sensitive and easier to use than the forerunner in either laboratory, and almost as accurate. The Geist-Blevin device attracted the attention of a manufacturer and won an IR-100 award in 1975. Its availability allowed NBS to discontinue the calibration of several total-irradiance lamp standards and helped many user groups to trace their measurements to SI units.

While working on the radiometer problem with Geist, Blevin collaborated with Bruce W. Steiner of the Heat Division on a suggestion to redefine the SI base unit for photometry, the candela, in terms of a specified number of lumens per watt, thus effectively transforming photometric standards into radiometric standards.[303]

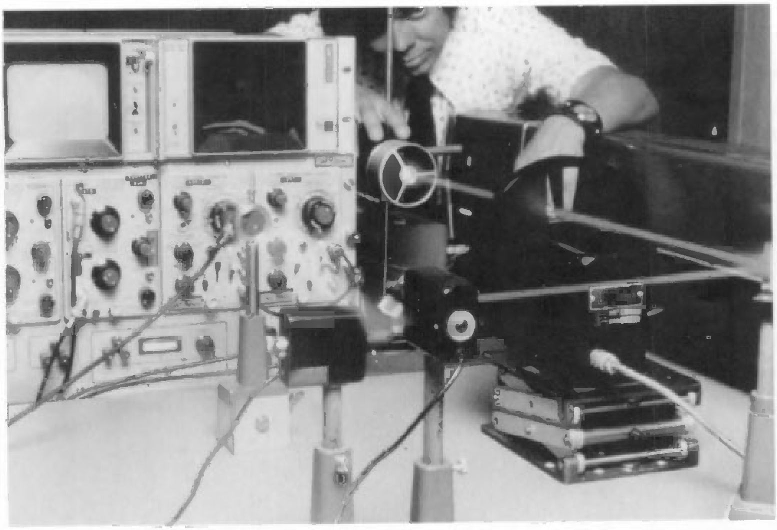
[299] J. Geist, L. B. Schmidt, and W. E. Case, "Comparison of the laser power and total irradiance scales maintained by the National Bureau of Standards," *Appl. Opt.* **12**, 2773-2776 (1973).

[300] D. C. Ginnings and M. L. Reilly, "Calorimetric measurements of thermodynamic temperatures above 0 °C using total blackbody radiation," *Temperature, Its Measurement and Control in Science and Industry,* **Vol. 4, Part 1**, H. H. Plumb, editor, pp. 339-348 (1972).

[301] R. J. Phelan, Jr. , and A. R. Cook, "Electrically calibrated pyroelectric optical-radiation detector," *Appl. Opt.* **12**, No. 10, 2494-2500 (1973). See also C. A. Hamilton, R. J. Phelan, Jr. , and G. W. Day, "Pyroelectric radiometers," *Opt. Spectra* **9**, No. 10, 37-38 (1975).

[302] J. Geist and W. R. Blevin, "Chopper-stabilized null radiometer based upon an electrically calibrated pyroelectric detector," *Appl. Opt.* **12**, 2532 (1973).

[303] W. R. Blevin and B. Steiner, "Redefinition of the candela and the lumen," *Metrologia* **11**, 97-104 (1975).



Robert J. Phelan used the electrically calibrated pyroelectric optical-radiation detector that he developed with colleagues at the NBS Boulder laboratories.

The success of the collaboration on the new radiometric instrumentation impelled Steiner, Geist, Russell Schaefer, and Edward Zalewski to form a research effort intended to improve the accuracy, reliability, and versatility of radiometric and photometric measurements. Eventually the project developed into a more formal collaboration called the Electro-Optical Radiometry Group.

Lasers and Photodiodes

Some time after their introduction, photodiodes became known as highly stable detectors of radiation—more stable, in fact, than the lamps NBS used to calibrate them. Less happy features of the devices were large variation in response with source position, angle of incidence, and wavelength. Seeking to overcome these problems through the use of lamps, monochromators, and filters was tough going because the energy content of the resulting beam was too low for accurate measurement.

Having learned to measure laser energies accurately during their earlier experiments, Geist, Steiner, Zalewski, and Antonio Corrons, a guest worker from Spain, in 1975 adopted the use of lasers as sources for photodiode-response measurements. Their technique involved the use of an electrically calibrated pyroelectric radiometer for the calibration of the response of a silicon photodiode. The group irradiated the photodiode with a wavelength-tunable cw dye laser through an interference filter. The laser provided substantially more power than had the lamps tried earlier, improving substantially the accuracy of the measurements. A wedge-shaped beam splitter and a second photodiode used to monitor the laser beam proved satisfactory in compensating for the natural temporal variation in the beam intensity of the laser.[304]

The calibrated photodiodes became useful in measurements of the spectral irradiance of NBS lamp standards, used at the Bureau to reproduce the irradiance of the gold-point blackbody source at 602 nm. The uncertainty of the lamp standards, about 1 %, was degraded only to 1.3 % by the introduction of the photodiode detectors, demonstrating for the first time the suitability of the dye-laser approach to calibrations of spectral irradiance a well as the utility of lasers for radiometry.

Later, Michael A. Lind, Edward Zalewski, and Joel B. Fowler adapted the electro-optical modulator stabilizer, devised in the Boulder laboratories, to reduce the variation with time of laser energy emission. The technique—use of intensity-stabilized tunable dye lasers and discretely tunable ion lasers with electrical substitution radiometers to characterize photodiodes—proved successful and was still in use years later for measurements at the highest accuracy levels.

Self-Calibration With Silicon Photodiodes

Continuing to advance the understanding of photodiode response, the NBS radiometry group assembled in 1977 a set of *Detector Response Intercomparison and Transfer* (DRIT) packages. Each package contained a photodiode-filter combination calibrated at the Bureau with ion-laser lines. NBS customers measured the photodiode response using their own instruments and reference standards, in accord with an NBS-prescribed protocol, then returned the results to the NBS radiometry group for analysis. The Bureau team examined the data, providing an evaluation of the customer's measurement capability and especially highlighting any apparent errors found in the customer's procedures.[305]

The new DRIT package nicely complemented the NBS calibration trend that passed beyond the calibration of reference standards towards analysis of a client's in-house measurement techniques—the procedure known generically as *Measurement Assurance Programs.*

In the course of studies of the physics of photodiodes, the NBS radiometry group discovered a method by which they could use the quantum efficiency of certain silicon photodiodes to create natural radiometric standards. In some cases, the uncertainty involved in the method was as low as 0.1 %.[306]

In 1984, Zalewski and Warren Gladden used the "self-calibration" method to calibrate a spectroradiometer with the 633 nm helium-neon laser line. The spectroradiometer was composed of an integrating sphere, a monochromator, and a photo-multiplier tube. The two then used the spectroradiometer to measure the

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[304] J. Geist, B. Steiner, E. Zalewski, and A. Corrons, "Electrically based spectral power measurements through use of a tunable cw laser," *Appl. Phys. Lett*. **26**, 309 (1975).

[305] M. A. Lind, E. F. Zalewski, and J. B. Fowler, "The NBS detector response package: the instrumentation," *NBS Technical Note 950,* July 1977, 23 pp.

[306] J. Geist, E. F. Zalewski, and A. R. Schaefer, "Spectral response self-calibration and interpolation of silicon photodiodes," *Appl. Opt*. **22**, 3795 (1980).

spectral irradiance, at the same wavelength, of an NBS spectral-irradiance standard lamp. Since the lamp had been calibrated against a gold-point blackbody source, it was possible to compare the two methods directly; they agreed within 1.1 %. This was the first time such a comparison had been accomplished. It showed the value of the laser calibration of spectroradiometers.[307]

The self-calibration method was tested further in 1984 by Henry J. Kostkowski, J. L. Lean, Schaefer, Robert D. Saunders, and Lanney Hughey. Using a self-calibrated, filtered photodiode equipped with an integrating sphere, the group measured the spectral irradiance of a standard lamp, traceable to a gold-point blackbody source, and they measured the spectral irradiance of the radiation from the storage ring of the Synchrotron Ultraviolet Research Facility, version II (SURF-II), for which the spectral irradiance could be calculated. All of the measurements agreed within 1 %.[308]

The self-calibration method developed by Zalewski and Gladden proved so easy to use that it rapidly became a favorite within the international radiometry community. Only the cryogenic radiometer at the National Physical Laboratory in England was its equal in accuracy. A 1988 international comparison of measurements in 11 countries, 6 based on self-calibration and 5 on electrical-substitution radiometry, showed good agreement. Nine of the results agreed within 0.15 %, a distinct improvement over results obtained 20 years earlier.

High-Temperature Superconductivity

The discovery that superconductivity, long thought to be a phenomenon restricted to temperatures below 20 K, could exist at much higher temperatures brought visions of lossless power transmission, revolutionary transportation systems, and exotic industrial and scientific devices during the late 1980s.

A Presidential Initiative

President Ronald Reagan, generally skeptical about the value of non-military government activity, paid a surprise visit to a Federal Conference on Commercial Applications of Superconductivity on July 28, 1987. The Federal government, he announced, should strive mightily to develop and commercialize the field of high-temperature superconductivity.

Reagan proposed an 11-point initiative on superconductivity, partly legislative and partly executive. He requested legislation to expand the *National Cooperative Research Act* to encompass new joint industrial-governmental production avenues; to increase

[307] E. F. Zalewski and W. K. Gladden, "Absolute spectral irradiance measurements based on the predicted quantum efficiency of a silicon photodiode," *Optica Pura Y Aplicada* **17**, No. 2, 133-140 (1984).

[308] H. J. Kostkowski, J. L. Lean, R. D. Saunders, and L. R. Hughey, "Comparison of the NBS SURF and tungsten ultraviolet irradiance standards," *Appl. Opt.* **25**, No. 18, 3297-3306 (1986). See also A. R. Schaefer, R. D. Saunders, and L. R. Hughey, "Intercomparison between independent irradiance scales based on silicon photodiode physics, gold-point blackbody radiation, and synchrotron radiation," *Optical Engineering* **25**, No. 7, 892-896 (1986).

patent protection for manufacturing processes; and to exempt from the *Freedom of Information Act* commercially valuable scientific and technical information on high-temperature superconductivity.

On the executive side, Reagan proposed a number of steps:

- To establish an Advisory Group on Superconductivity, by which "Wise Men" could counsel the White House on research and commercialization policies.
- To establish several Superconductivity Research Centers to conduct basic research and serve as focal points for information on superconductivity. Four centers would arise within the Department of Energy—at the Argonne National Laboratory, at the Lawrence Berkeley Laboratory, at the Iowa Ames Laboratory, and in the DoE headquarters where a database would be created. The Department of Commerce was directed to establish a center devoted to electronic applications of high-temperature superconductivity at NBS/Boulder. Other activities in the program would take place in the National Aeronautics and Space Administration, in the National Science Foundation, and in the Department of Defense (the DoD was expected to invest $150 million in development of superconductive technology over a 3-year period).
- To urge all Federal agencies to help create and transfer to industry new technology based upon superconductivity.
- To establish accelerated processing procedures within the U.S. Patent and Trademark Office for superconductivity inventions.
- To urge NBS specifically to assist the program by the expeditious development of appropriate physical and reference standards and technical data, and to focus efforts on devices for the detection and measurement of low-level magnetic fields.
- To encourage all agencies to reallocate Fiscal 1987 funds to accelerate basic and applied superconductivity research.

Scientists at NBS responded enthusiastically to the encouragement of President Reagan, although they could accurately claim that the field of superconductivity had seen considerable action at the Bureau for more than a half-century.

Robert A. Kamper, chief of the Electromagnetic Technology Division in Boulder and himself a long-time student of superconductivity, gave his perspective to the topic:[309]

> The Bureau has been studying and measuring the properties of superconducting materials for more than three decades. While the new materials hold great commercial promise, the superconductor industry already registers annual sales of about $200 million. The measurement standards and methods that support

[309] Mark Bello, "Riding a Heat Wave: Researchers Take Another Look at Superconductivity," pp. 5-13 in "NBS Research Reports," *NBS Special Publication 733,* August 1987, 32 pp.

manufacturing and commerce in this industry were developed here. We also have developed several superconducting devices, including what is probably the world's largest working array of Josephson junctions—a series of 14,184 junctions that can produce a precise 10-volt standard of electricity.
Our expertise and measurement capabilities in areas crucial to exploiting this tremendous opportunity will support U.S. industry's efforts to surmount the many obstacles that must be overcome before the new high-temperature superconductors can be put to practical use.

Laboratory work on high-temperature superconductors followed several paths at NBS: study of the crystallographic phase relationships in the materials comprising high-temperature superconductors; measurements of the critical current densities of various high-temperature superconductors; and preparation of devices based on the use of high-temperature superconductors.

Phase Diagrams of High-Temperature Superconductors

The new superconductor materials were brittle ceramics, generally polycrystalline. Forming such materials into wires, thin films, and bulky structures would not be an easy task. Francis W. Beech, Salvatore Miraglia, Antonio Santoro, and Robert S. Roth prepared a comprehensive phase diagram of one material, $YBa_2Cu_3O_{9-\delta}$, showing its structure to be orthorhombic. Their determinations were made by analyzing neutron-diffraction results from powder samples at the NBS nuclear reactor.[310]

Other phase transition studies, structure analysis, and observations of crystal growth were accomplished in several groups:

- Roger L. Stockbauer and Richard Kurtz of the Surface Science Division, in collaboration with David L. Ederer of the Radiation Physics Division.
- A group led by Robert Roth of the Ceramics Division.
- A group led by Hassel M. Ledbetter of the Fracture and Deformation Division.
- Stanley Block and Gasper J. Piermarini of the Ceramics Division.

In some cases, the chemical composition of the superconductor materials was uncertain, let alone the crystal structure.

Instruments and Machines

The high-temperature superconductivity program in Boulder grew out of an older program which utilized "ordinary" superconductivity for the creation of new instruments and machines. The discovery of high-transition-temperature materials simply presented new options for the program.

[310] F. Beech, S. Miraglia, A. Santoro, and R. S. Roth, "Neutron study of the crystal structure and vacancy distribution in the superconductor $Ba_2YCu_3O_{9-\delta}$," *Phys. Rev.* **B35**, No. 16, 8778 (1987).

Soon after the announcement of superconductivity in yttrium barium copper oxide (YBCO) by Wu and Chu in 1987, James E. Zimmerman re-thought an earlier decision to retire. With some of his old colleagues, he devised a mechanical method to form the superconducting weak link required for a superconducting quantum interference device (SQUID). The resulting instrument was a sensitive magnetic sensor. When President Reagan paid his visit—mentioned earlier in this section—to the Federal Conference on Superconductivity, he attended a demonstration of the new device.[311]

Impressive as it was, the new magnetic sensor needed an important modification. For routine use, such an instrument should be constructed with a more stable thin-film link. Ronald H. Ono and a group of colleagues subsequently developed a practical junction consisting of two YBCO films sandwiching a thin barrier of normal conductor. The new SQUID proved operable at frequencies up to 9 THz.[312] The advance merited a Department of Gold Medal Award, presented to the entire team in 1993.

Another early application of YBCO to instrumentation was a bolometer for radiation detection.[313]

Soon after the discovery of superconductivity in YBCO, Jack W. Ekin investigated its current-carrying properties. He found that "weak links" existing between the grains of the polycrystalline material controlled the current flow. This discovery led to a world-wide effort to characterize the phenomenon and, if possible, to mitigate its effect.[314] The paper describing that work received many citations in subsequent superconductivity publications. The investigation led directly to new approaches to electronic and power applications. Robert L. Peterson and Ekin contributed to the theoretical understanding of the "weak link" model.[315]

Ekin and his colleagues Panson and Blankenship of the Westinghouse Research Laboratories also learned how to use noble metals to decrease the resistance of electrical contact in the new materials, enhancing their ability to transport large currents.[316]

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[311] J. E. Zimmerman, J. A. Beall, M. W. Cromar, and R. H. Ono, "Operation of a Y-Ba-Cu-O rf SQUID at 81 K," *Appl. Phys. Lett.* **51**, pp. 617-618 (1987).

[312] R. H. Ono, J. A. Beall, M. W. Cromar, T. Harvey, M. Johansson, C. Reintsema, and D. Rudman, "High T_c SNS Josephson microbridges with high resistance normal metal links," *Appl. Phys. Lett.* **59**, p. 1126 (1991).

[313] J. C. Brasunas, H. W. Moseley, B. Lakew, R. H. Ono, J. A. Beall, J. E. Sauvageau, and D. G. McDonald, "Fabrication and operation of a high T_c composite bolometer," *J. Appl. Phys.* **66**, p. 4551 (1989).

[314] J. W. Ekin, A. I. Braginsky, A. J. Panson, M. A. Janocko, D. W. Capone, N. J. Zaluzec, B. Flandermeyer, O. F. Delima, M. Hong, J. Kwo, and S. H. Liou, "Evidence for weak link and anisotropy limitations on the transport critical current in bulk polycrystalline YBCO," *J. Appl. Phys.* **62**, pp. 4821-4828 (1987).

[315] R. L. Peterson and J. W. Ekin, "Josephson junction model of critical current in granular $YBa_2Cu_3O_7$ superconductors," *Phys. Rev.* **B37**, p. 9848 (1988). See also R. L. Peterson and J. W. Ekin, "Airy pattern, weak link modeling of critical current in high T_c superconductors," *Physica* **C157**, pp. 325-333 (1989).

[316] J. W. Ekin, T. M. Larson, N. F. Bergren, A. J. Nelson, A. B. Schwartzlander, L. L. Kazmerski, A. J. Panson, and B. A. Blankenship, "High T_c superconductor/normal metal contacts with surface resistivities in the $10^{-10}\ \Omega\ cm^2$ range," *Appl. Phys. Lett.* **52**, p. 1819 (1998).

The traditional role of NBS/NIST—development of definitive measurement and test methods—was filled for the new materials and devices by Ronald Goldfarb, who showed that ac susceptibility measurements were particularly advantageous for ceramic superconductors. Loren F. Goodrich and Steven L. Bray helped in this respect, too, describing at length the special measurement problems associated with the measurement of critical current, and recommending the adoption of specific methods as standard practice.[317] The efforts of Goodrich Bray and were incorporated into two international standards for high-temperature superconductors.

Other Properties of High-T_c Superconductors

Among the high-temperature superconductivity projects undertaken at the Bureau were the synthesis of samples and the dependence of the superconductive properties on magnetic fields using microwave absorption, by a group led by Lawrence H. Bennett;[318] critical currents, by Robert L. Peterson and Jack W. Ekin;[319] and electron tunneling in thin films and bulk samples, by groups led by Richard Harris and by John Moreland.[320]

Russell C. Casella pursued the theory underlying the new superconductors, which in many ways seemed not to follow the usual Bardeen-Cooper-Schrieffer theory of superconductivity.[321]

Recycling to Save Energy and Materials

America knew in those days that it could extend the useful lives of many products to conserve natural resources and to save energy; for many families, recycling was a routine practice. At NBS, however, science undergirded recycling and resource recovery; staff members evaluated products and processes to maximize the conservation of energy.

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[317] R. B. Goldfarb, A. F. Clark, A. I. Braginski, and A. J. Panson, "Evidence for two superconducting components in oxygen annealed single phase Y-Ba-Cu-O," *Cryogenics* **27**, p. 475 (1987). See also L. F. Goodrich and S. L. Bray, "High T_c superconductors and critical current measurements," *Cryogenics* **30**, pp. 667-677 (1990).

[318] F. J. Adrian, J. Bohandy, B. F. Kim, K. Moorjani, J. S. Wallace, R. D. Shull, L. J. Swartzendruber, and L. H. Bennett, "Magnetic field dependence of the superconductivity in Bi-Sr-Ca-Cu-O superconductors," *Physica* **C156**, 184-188 (1988).

[319] R. L. Peterson and J. W. Ekin, "Josephson-junction model of critical current in granular $YBa_2Cu_3O_{7-\delta}$ superconductors," *Phys. Rev.* **B37**, No. 16, 9848-9851 (1988).

[320] J. Moreland, R. H. Ono, J. A. Beall, M. Madden, and A. J. Nelson, "Evidence for the superconducting proximity effect in junctions between the surfaces of $YBa_2Cu_3O_x$ thin films," *Appl. Phys. Lett.* **54**, No. 15, 1477-1479 (1989).

[321] R. C. Casella, "Theoretical models for high-temperature superconductivity," *Il Nuovo Cimento* **10**, No. 12, 1439-1448 (1988). See also "Comparison of interplanar-boson-exchange models of high-temperature superconductivity: possible experimental tests," *Applied Phys. Lett.* **55**, No. 9, 908-910 (1989).

Recycling Oil to Save Energy

The Bureau became involved in recycled oil as a result of the *Energy Policy and Conservation Act of 1975* (PL 94-163). This act called upon the Federal Energy Administration to direct NBS in the development of appropriate test procedures relating to energy conservation, including recycled oil. Federal Energy Administration officials estimated that oil re-use could reduce oil imports by about 70,000 barrels each day. At NBS, the mission of a *Recycled Oil Program,* formed in 1976 in the Institute for Materials Research with Donald A. Becker at its head, was to develop test procedures for the determination of the equivalency of re-processed oil and new oil.

In November 1976 NBS held a workshop on *Measurements and Standards for Recycled Oil.* Some 26 presentations by technical experts from both government and industry were divided among seven sessions. Nearly 70 attendees represented government agencies, engine manufacturers, petroleum refiners, heavy industry, and standards groups.[322]

A second workshop was held in November 1977. Considerable progress was reported in identifying the details of the recycling problem; for example, it was understood that the end use of the recycled oil—for fuel, for engine lubrication, for industrial use, or for hydraulics—dictated different levels of purification. Much of this progress resulted from NBS studies of recycled oil.

A third conference, co-sponsored by NBS, the American Society for Testing and Materials, and the Mechanical Failures Prevention Group, was held at the Bureau in October 1979. By that time, NBS had completed its study of recycled oil for use as fuel and had transmitted test procedures for that use to the Federal Trade Commission. The Bureau staged a fourth conference in 1982, which provided closure to the topic of recycled oil by 1984.

A new piece of legislation, the *Used Oil Recycling Act of 1980,* Public Law 96-463, provided new directions for NBS:

- The Bureau retained responsibility for determining the quality of recycled oil.
- NBS was forbidden to identify oil as recycled until the entire study was complete and the Federal Trade Commission had developed labeling rules.
- The new act also mandated assessment by the Bureau of environmental problems caused by improper disposal or reuse of recycled oil, analysis of the supply and demand for used oil, and comparison of energy savings associated with new or refined used oil.

During the lifetime of the recycled oil project, NBS was instrumental in forming a new technical division of the American Society for Testing and Materials. Bureau scientists also developed equipment and techniques for the chemical, physical, and thermal treatment and analysis of oils, and they contributed to the success of similar work in other laboratories.

[322] "Measurements and Standards for Recycled Oil," *NBS Special Publication 488,* D. A. Becker, editor, August 1977, 140 pp.

NBS contributors to the recycled oil program were many: Donald Becker (program manager); Reenie M. Parris, Franklin R. Guenther, Willie E. May, Charles S. Ku, Ronald F. Fleming, and Stephen N. Chesler (chemical analysis); Stephen J. Weeks and Stephen M. Hsu (mathematical analysis); Arthur L. Cummings and Patrick Pei (test methods); John J. Comeford, James A. Walker, Wing Tsang, Laszlo E. Szegvary, and David B. Clark (thermal analysis); Lewis K. Ives, Richard S. Gates, Paul A. Boyer, and Arthur W. Ruff (physical analysis).

NBS Opens an Office of Recycled Materials

During its discussion of the *Resource Conservation and Recovery Act of 1976* (PL 94-580), members of Congress voiced the idea of locating in the Department of Commerce some or all of the research and development work connected with the act. This they did, calling upon the Secretary of Commerce to provide guidelines for specifications for recovered materials, to stimulate markets for recovered materials, to promote proven recovery methods, and to generate a forum for the discussion of technical and economic information on resource recovery. In turn, the Secretary delegated much of the responsibility to NBS.

By November 1976 the Bureau had established a *Resource Recovery Program.* In 1978 the activity was expanded to include the *Recycled Oil Program.* The new entity was given the name Office of Recycled Materials (ORM); located in the National Measurement Laboratory, it was temporarily placed under the command of Donald R. Johnson. In 1979, a Technical Advisory Center was created within the ORM to determine suitable market locations for recycled materials and to establish a database for technical and economic resource recovery systems.

NBS had discharged nearly all of its responsibilities under the 1976 Resource Recovery Act by the end of Fiscal Year 1982. Accordingly, the Office of Recycled Materials was disbanded at that time. [323]

The major activities undertaken by ORM during its 6-year life included the following:

- Study of recycled oil.
- Study of the recycling of municipal solid waste.
- Study of the recycling of industrial wastes.
- Studies of the recovery and disposal of hazardous wastes.
- Probing markets for recovered materials.
- Evaluating the commercial feasibility of resource recovery facilities.
- Assisting in the formation of pilot resource recovery program for the state of California.

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[323] "The National Bureau of Standards Office of Recycled Materials 1976-1982," Harvey Yakowitz, editor, *NBS SP 662*, September 1983, 634 pp.

Recovering Energy From Municipal Wastes

American consumers generated about 150 million tons of solid waste per year during the period 1976-82. Another estimated 50 million tons of waste was designated as hazardous. The Bureau collaborated with other resource-recovery agencies in an effort to separate usable materials and energy from municipal solid waste. The effort extended to metals—aluminum and ferrous metals—and to glass. In addition, there were efforts to recover energy from the combustion of the organic waste fraction.

An eddy-current method proved useful in removing aluminum from the waste stream. Aluminum often was used to manufacture soft drink cans; the metal could be recovered at purity levels useful as feed stocks for aluminum refiners. Electromagnetic separation could be used to remove ferrous metals. Glass often could be recovered as a heavy fraction once the metals were removed.

Bureau scientists undertook the problem of determining the energy available from the combustion of the organic fraction of municipal solid waste. Duane R. Kirklin and Eugene S. Domalski built an oxygen bomb calorimeter to accommodate 25 g samples of *Refuse Derived Fuel,* pellets prepared by compressing pre-processed solid waste. In collaboration with David J. Mitchell, they found experimental values averaging 25 MJ/kg for the fuel. The results seemed not to depend upon processing methods.[324] With the assistance of Jennifer C. Colbert, P. Decker, H. Xiheng, and Stanley Abramowitz, the scientists verified the early results by examining more than 100 samples and calibrating the calorimeters.

Construction, testing and use of a large-scale flow calorimeter were accomplished in 1981-82 by Domalski, Kirklin, Colbert, Kenneth L. Churney, Martin L. Reilly, Albert E. Ledford, Russell V. Ryan, and Donald D. Thornton.[325] Four members of the group—Churney, Ledford, Reilly, and Domalski—received the Department of Commerce Silver Medal Award in 1984 for the development of the large-scale calorimeter.

The Beginning of "Technology Transfer"

From its founding, Bureau scientists communicated results of their investigations to the American—and, in many cases, the foreign—public. Sometimes the communication took place through the publication process. Other times it arose from a collaboration with an outside organization. Frequently, industrial associations were keenly interested in the progress of NBS work in particular areas.

During the 1970s and 1980s, however, the idea began to take hold that there should be direct connections between NBS projects and American industry in ways that previously had not been considered. In this section we note the growth of that idea.

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[324] D. R. Kirklin and E. S. Domalski, "A 25-gram-capacity oxygen- bomb calorimeter," *Resources and Conservation* **10**, 177-187 (1983).

[325] K. L. Churney, A. E. Ledford, M. L. Reilly, and E. S. Domalski, "multi-kilogram-capacity calorimeter for heterogeneous materials," *J. Res. NBS* **91**, 277-298 (1986).

A Change in Emphasis

It became clear to the Bureau's managers while Ernest Ambler was director that NBS should begin to express its output in terms of "technology transfer"—identifying directly those activities that allowed industry or other government agencies to make use of scientific or engineering advances.

Looking at itself with new eyes in the early 1980s, NBS found many projects and programs that fitted the definition handily. Among them were the following:

- *Calibration Services,* which allowed other organizations to measure their own capabilities in dozens of technical areas against those of the Nation's leading measurement laboratory. The Bureau, selling the calibration services at cost, realized millions of dollars annually from this program.

- *Measurement Assurance Programs,* developed by NBS as a means of verifying not only the reference devices used by outside organizations but the latter's measurement practices as well. These enabled users to compare their measurement results against those obtained by Bureau scientists.

- *Standard Reference Materials,* which allowed other organizations to obtain samples chosen from a list of 1000 well-characterized materials or devices for use in their own plants or laboratories as reference devices. During Fiscal 1980, NBS sold about 40,000 SRM units to more than 10,000 users worldwide.

- *Standard Reference Data,* which gave outsiders access to technical data evaluated by experts for its accuracy and reliability. More than 20 data centers, located at NBS or elsewhere, screened thousands of literature references for the most reliable information.

- *Standards Information Service,* a reference collection of more than 200,000 standards, specifications, test methods, codes, and recommended practices issued by U.S. technical societies, professional organizations, State standards offices, Federal agencies, and international organizations.

- *Energy-Related Inventions,* a program in which experts reviewed plans submitted by individuals or small businesses. The free service, arising from the *Federal Nonnuclear Energy Research and Development Act of 1974,* resulted in the examination of more than 3000 ideas in 1980; some 30 were referred to the Department of Energy for further study.

- The *Research Associate Program,* under which personnel sponsored by industry, professional, or trade organizations were accepted for cooperative study with NBS scientists. Bureau laboratories and other facilities were made available for use by the associates. In addition, they enjoyed daily contact with NBS scientists and engineers. Since 1921, more than 1000 individuals participated in the program.

- Liaison with State and local governments in the areas of weights and measures, construction, and environmental measurements led to other communication as well. The government officials learned of NBS ideas and practices in unexpected areas such as fire-fighting and fire prevention, energy conservation, computers, and resource recovery.

- The *Postdoctoral Research Associates* program, which brought to NBS for one or two years some of the Nation's most promising young scientists and engineers. The associates worked with the most senior project leaders at the Bureau under the auspices of the National Research Council.

- The *Guest Worker* program, which allowed visitors from U.S. or foreign laboratories to work on specific projects for periods as short as a few months or as long as 2 years.

- Conferences, tours, exhibits, and technical films, which carried information from NBS to citizens and non-citizens at all levels of scientific sophistication.

All told, technology transfer became identifiable as an integral part of daily life at NBS.

Automated Manufacturing Research Facility

As the manufacture of machine tools, aircraft, and automobiles became—perhaps paradoxically—more automatic and yet more intricate, measurement of the component parts became more complex as well. In the United States, most of the companies involved in parts manufacture employed fewer than 50 people. As automated manufacturing became more necessary to meet growing competition for business, such companies found it increasingly difficult to cope with the demands imposed by short-run, automated operations. But the complexity of automated manufacturing was felt by government agencies and large companies, too. NBS provided help with automation to all comers.

In a new Bureau facility known as the Automated Manufacturing Research Facility (AMRF), located in the main instrument shop, researchers in the National Engineering Laboratory developed protocols for the standardization of automated, small-quantity manufacturing that addressed the use of numerically controlled metal machining, robotic parts handling, in-plant conveyors, and software compatibility. The AMRF[326] was one of the largest and most influential progams ever undertaken at NBS, rivaling in many ways the wartime efforts in proximity-fuse and guided-missile development.

[326] J. Simpson, R. Hocken, and J. Albus, "The Automated Manufacturing Research Facility of the National Bureau of Standards," *J. Manufacturing Systems* **1**, 17-31 (1982).

The AMRF involved dozens of innovative scientists and engineers under the capable leadership of John A. Simpson. Protocols developed in the AMRF allowed the small manufacturer to compete with larger firms that employed process-development staffs, and they allowed large companies and government agencies to undertake automation projects that otherwise would have been beyond their reach.[327]

In developing new manufacturing measurement methods, Bureau experts initially worked with representatives of a dozen companies, using equipment lent by the firms and involving their personnel in the development through the research associate program. Equipment located in a Turning Center work station could be used to produce in half an hour parts that took as long as 17 hours with manual methods. In some cases, the need for spare-parts inventory could be entirely eliminated.

The AMRF also included a test bed to solve problems associated with interconnecting components used in computer-aided manufacturing systems and connecting those systems to design, planning and control operations. The most significant problems arose from the need to develop the software used to interconnect devices made by different companies. The interfaces had to be effective without exposing proprietary software. Continuous contact with industrial standards bodies permitted the development of such standards as the Initial Graphics Exchange Specification, mentioned earlier, that enabled all manufacturers to utilize computerized processing.

Eventually the AMRF became a $50 M technical research program that directly involved Industrial Research Associates from 50 firms and produced 18 patents and dozens of technical papers.[328]

According to a 1990 report of the National Academy of Science, the AMRF "catalyzed" the transition of NBS into NIST:[329]

> The AMRF has for years served as a platform to develop needed technology for flexible, integrated, and automated manufacturing of discrete parts. It has played a significant role in the identification and development of emerging technologies in manufacturing. It has had considerable influence on various private efforts throughout the nation. It was also the catalyst in the legislative process that resulted in the Technology Competitiveness Act.

[327] For a general discussion of the AMRF, see Michael A. Baum, "Manufacturing Technology for the Second Industrial Revolution," pp. 16-21 in "NBS Research Reports," *NBS Special Publication 721,* April 1987, 32 pp.

[328] P. N. Nanzetta, "Technology transfer from the Automated Manufacturing Research Facility at the National Institute of Standards and Technology," in *Control and Dynamic Systems: Advances in Theory and Applications.* Vol 45, Manufacturing and Automation Systems (Academic Press, 1992).

[329] "An assessment of the National Institute of Standards and Technology Programs, Fiscal Year 1990," *National Academy Press,* Washington, DC, 1991.

Measurements for Chemical Processing

During the early 1980s, Bureau researchers developed new methods for measurements involving the flow of multi-phase materials. Many chemical processes involved mixtures of solids and fluids; techniques for the determination of properties such as composition, viscosity, temperature, and density were necessary for effective process design and control.

Calibration of instruments used in process-control measurements presented special problems because of the complex nature of many of the process streams. With the American Petroleum Institute, for example, scientists in the National Engineering Laboratory (NEL) prepared a database for use in evaluating the performance of orifice meters—used in gas pipelines to measure flow rates and establish equity in the transfer of metered gases.

In a related activity, NEL scientists developed a predictive model that incorporated properties such as density, thermal conductivity, and viscosity of whole classes of industrial mixtures—chemicals such as alcohols, ethylene, vinyl chloride, both natural and synthetic gases, and even such complex mixtures as those derived from tar sands, coal, and oil shale. The model was immediately adopted by the Gas Processors Association. The NBS Office of Standard Reference Data assisted in its distribution to interested firms.

To broaden the database used in the design of pumps, heat exchangers, compressors, and pipeline architecture, other NEL scientists designed and built an apparatus for the direct measurement of thermodynamic properties of hydrocarbon, chemical, and petrochemical fluids at temperatures up to 900 K and pressures as high as 35 MPa. Materials of special interest to particular industry groups could be studied in the facility, yielding key design data.

Sharing NBS Facilities

NBS management became more conscious in the mid-1980s of a new trend in the U.S. government with respect to Bureau interactions with private companies. No longer—as was the case during the 1960s—were NBS scientists required to beware of charges of favoritism if they collaborated too closely with industrial colleagues. Gradually, as the effectiveness of the close government-industry cooperation in other countries—especially Japan—became clear, cooperation between NBS researchers and representatives of individual firms was tolerated, then encouraged. Eventually, Bureau laboratories were made available for proprietary industrial research.

Ernest Ambler recalled especially an admonition delivered in the 1983 Packard report (mentioned earlier in this chapter) encouraging increased access to Federal facilities for industrial and academic projects. The Bureau responded to that exhortation by expanding its programs for *Industrial Research Associates,* its cost-shared projects with industry, and the use of NBS facilities by industrial and government scientists and engineers.[330]

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[330] Ambler, *SP 825*, p. 33.

One example that illustrated the new trend in the use of NBS laboratories by outsiders was the issuance of *NBS Special Publication 682,* "Facilities of the National Bureau of Standards. " In the foreword to the publication, Director Ambler stated:

> As the nation's foremost science and engineering laboratory, the National Bureau of Standards has some of the premier research and testing facilities in the United States. Many of the facilities are available for use by the scientific and engineering communities either on a cooperative or independent basis. Now, recognizing the strong challenges from abroad and the need for U.S. researchers to pool their resources, we have decided to make selected NBS facilities available to U.S. researchers for proprietary work on a cost-recovery basis, when equal or superior facilities are not otherwise readily available.

In this first venture into uncharted waters, the Bureau listed two dozen of its strongest experimental installations, along with the names of appropriate contact personnel. These included:

- The NBS Research Reactor, providing a peak thermal neutron flux of 4×10^{14} neutrons per cm^2 (contact person, Robert S. Carter), along with a neutron depth profiling facility (Ronald F. Fleming), a high-resolution neutron diffractometer for use with powder samples (Edward Prince), and a small-angle neutron scattering facility (Charles J. Glinka).
- The 140 MeV Electron Linear Accelerator, providing electron beam power of 50 kW (Sam Penner).
- The Synchrotron Ultraviolet Radiation Facility-II, a 280 MeV electron storage ring providing photons of wavelengths 60 nm to 120 nm (Robert P. Madden).
- A metals-processing laboratory, with capabilities for inert gas atomization, electrohydrodynamic atomization, melt spinning, electron-beam and laser surface melting, hot isostatic pressing, and plasma-transferred arc coating (John R. Manning).
- Toxic chemicals handling laboratory, with the capability for safe use of dangerous materials (Willie E. May).
- High-voltage measurement facility, with capabilities for direct voltages up to 300 kV, 60 Hz alternating voltages up to 175 kV, and lightning pulses up to 500 kV (Robert E. Hebner).
- Transverse electromagnetic cells (Mark T. Ma, NBS/Boulder).
- Electromagnetic anechoic chamber, for field strengths up to 100 V/m at frequencies from 200 MHz to 18 GHz (Norris S. Nahman, NBS/Boulder).
- Ground-screen antenna range, enclosed by an air-inflated non-metallic cover for all-weather use (Norris S. Nahman, NBS/Boulder).
- Near-field scanning facility for antenna measurements, (Allen C. Newell, NBS/Boulder).

Robert P. Madden checked a connecting flange on the Synchrotron Ultraviolet Radiation Facility-II

- Outdoor extrapolation range for antenna measurements, featuring 6 m towers with separation variable up to 60 m (Allen C. Newell, NBS/Boulder).
- Automated Manufacturing Research Facility, with three machining centers, a coordinate-measuring machine, a cleaning/deburring station, and robotic handling system (Philip N. Nanzetta).
- Fire research facilities with heat-release calorimeters, a room/corridor smoke-and-gas station, a 2.4 m by 3.7 m by 2.4 m burn room and smaller subsidiary rooms, two pilot furnaces, reduced-scale physical models, and a two-story structural steel facility (Jack E. Snell).
- Plumbing Research Laboratory, a five-story plumbing stack (Lawrence S. Galowin).
- Large Environmental Chamber, with static and dynamic temperature and humidity profile capability (Tamami Kusuda).
- Line heat-source guarded hot plate, with a temperature variable over 200 °C (Thomas K. Faison or Douglas Burch).
- Acoustic Reverberation Chamber, 9 m by 7.6 m by 6 m with controlled environment (Simone L. Yaniv).

- Acoustic Anechoic Chamber, 6.7 m by 10 m by 6.7 m, with controlled humidity (Daniel R. Flynn).
- Network Protocol Testing and Evaluation Facility, for testing network protocols, satellite communications, high-speed and multi-processing networks, videotex, public data networks, network security, local area networks, and computer-based office systems (Robert P. Blanc).

It was an extensive list, containing facilities available nowhere else in America. The "arms-length" relationship formerly existing between U.S. industry and government was changing rapidly into an "arm-in-arm" relationship.

CHAPTER FIVE

THE NATIONAL BUREAU OF STANDARDS BECOMES THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY: PUBLIC LAW 100-418, AUGUST 23, 1988

A NEW MISSION AND A NEW NAME

Although he did not realize it, Luigi Crovini, chief of the thermometry program at the Italian national standards laboratory, spoke for many metrologists when he asked in 1988, "Is it true that the National Bureau of Standards is changing its name? This is a very strange thing, to discard a name that is known throughout the world as designating the best metrology laboratory."[1] The change puzzled many staff members at NBS, too.

However, the change should have come as no surprise. It was rooted in the growing awareness in Congress that the American enterprise was faltering in international competition. Many in Congress knew that foreign governments—far from worrying about the niceties of anti-trust legislation as the United States government had done for decades—joined wholeheartedly in the industrial programs of their countries, smoothing the way to success in international trade. Even members of Congress who decried the excesses of "big government"—an attitude long associated with the Republican party—became willing to marshal the resources of the Federal establishment for the benefit of U.S. industry.

Given the increased emphasis on international competitiveness, technology transfer, and industrial productivity in the dialog between NBS and Congress during the 1980s, new legislation to re-define the mission of the Bureau was almost a certainty. The change in the name of the agency—in the view of the Congress—merely served to underscore its new role within the Department of Commerce.

Following the Congressional elections of 1986, the Senate Commerce Committee—under its new chairman, Ernest Hollings of South Carolina—was determined to give additional responsibilities to NBS as one of several initiatives to improve American competitiveness in world-wide markets. As it happened, there were many members of both houses of Congress who had similar feelings about American agencies and practices. Considering activities as varied as educational methods, Patent Office regulations, and international fiscal policy, Senators and Representatives debated ways to cure the ills of the American economy.

[1] Luigi Crovini, Head of Thermometry, Istituto di Metrologia "G. Colonetti," Torino, Italy; private conversation with the author.

Months of effort—both in the Senate and in the House—to accomplish these multiple goals resulted in the *Omnibus Trade and Competitiveness Act of 1988,* Public Law 100-418.[2] Ten Titles covered a range of trade-related topics in more than 460 pages of text, representing an amalgamation of ideas from throughout Congress. The titles convey the breadth of the Act's intended reach:

- Title I. Trade, Customs, and Tariffs.
- Title II. Export Enhancement.
- Title III. International Financial Policy.
- Title IV. Agricultural Trade.
- Title V. Foreign Corrupt Practices Amendments, Investments, and Technology.
- Title VI. Education and Training for American Competitiveness.
- Title VII. Buy American Act of 1988.
- Title VIII. Small Business.
- Title IX. Patents.
- Title X. Ocean and Air Transportation.

For Bureau employees and their colleagues in the world's national metrological laboratories, the most significant of the provisions of Public Law 100-418 were to be found deep within Title V. Mimicking the Act itself, Title V addressed a mixture of ideas:

- Subtitle A. Foreign Corrupt Practices Act Amendments, Review of Certain Acquisitions.
- Subtitle B. Technology.
- Subtitle C. Competitiveness Policy Council Act.
- Subtitle D. Federal Budget Competitiveness Impact Statement.
- Subtitle E. Trade Data, Impact, and Studies.

The line that caught the attention of NBS employees was lodged in *Subtitle B. Technology* of Title V's disparate collection. *Subpart A of Part I, Subtitle B, Title V, PL 100-418* carried the heading "National Institute of Standards and Technology." Just like that, the "National Bureau of Standards" was no more.

An indication of congressional faith that NBS could play a significant role in a resurgent American presence in world trade can be found in a few lines of the text of Subpart A:

[2] 102 STAT. 1107, Public Law 100-418. Its 10 titles occupy 467 pages in the U.S. Statutes At Large. Title V, amending the NBS Organic Act, fills 26 pages.

> The National Bureau of Standards since its establishment has served as the Federal focal point in developing basic measurement standards and related technologies, has taken a lead role in stimulating cooperative work among private industrial organizations in efforts to surmount technological hurdles, and otherwise has been responsible for assisting in the improvement of industrial technology. It is the purpose of this Act to rename the National Bureau of Standards as the National Institute of Standards and Technology and to modernize and restructure that agency to augment its unique ability to enhance the competitiveness of American industry while maintaining its traditional function as lead national laboratory for providing the measurements, calibrations, and quality assurance techniques which underpin United States commerce, technological progress, improved product reliability and manufacturing processes, and public safety.

It was clear from the quoted text that Congress intended to add substantial new responsibilities to the NBS mission. There was no indication that the new assignments should replace existing ones.

When the announcement came, the great majority of NBS staff members were offended that Congress would change the name of the Bureau. Only a few read the text of PL 100-418. Some employees counseled Director Ernest Ambler to retain NBS as a title, as if it were his option. Others simply shook their heads at the apparent ease with which Congress cast aside nearly a century of tradition.

Foreign colleagues such as Luigi Crovini were thunderstruck that such a valued American "trademark" would be discarded. For them, "National Bureau of Standards" identified the ultimate in objectivity and accurate measurements.

Because of the widespread surprise caused by passage of Public Law 100-418, it is worthwhile to document the signs of its coming.

SIGNS OF IMPENDING CHANGE AT NBS

The *Omnibus Trade and Competitiveness Act of 1988* came as a shock to most NBS employees. For those who would see, however, the portents of change had been visible for years.

A Growing National Need

A key ingredient in the mandate for change—not simply in name, but in the Federal role for the Bureau as well—was the existence of a pressing National need. A pressing National need there was indeed, and it was a need of long standing. American industry had been out-sold for years by foreign competitors. Consumer goods led the list—automobiles, television sets, radios, audio and video players, electronic toys, clothing, and a raft of other items. The steel products, heavy tractor-based equipment, and many other construction items used by Americans quite often were manufactured outside the United States. By 1983, the balance of international trade had shifted dramatically away from America.[3] The following table comparing trade balances for several nations during the decade of the 1980s illustrates the magnitude of the shift.

Current Trade Balances (in billions of U.S. dollars)

Country	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
United States	6	–7	–44	–104	–113	–133	–144	–127	–106	–92
West Germany	–3	5	5	10	17	40	46	50	55	44
United Kingdom	15	8	6	3	5	16	–7	–27	–34	–24
Japan	5	7	21	35	49	86	87	80	57	36

Source: International Monetary Fund, quoted by Lester Thurow, *Head to Head: the Coming Economic Battle Among Japan, Europe, and America* (New York: William Morrow and Company, Inc. 1992) p. 231.

The Congress, with advice from many quarters, perceived the problem underlying the debilitating trade balance as one of declining American technology. A committee of the National Academy of Engineering (NAE) issued in the spring of 1988 a comprehensive report on the role of technological issues in American competitiveness.[4] In its report, the NAE committee—which included among its members John W. Lyons, then director of the NBS National Engineering Laboratory—urged the Federal government to:

> Use its diverse capabilities to broadly encourage the technological developments that are critical to sustaining the competitive interests of the nation. Efforts need to be focused through a designated entity that can effectively respond to industry initiatives and interact with non-government groups, including industry.

It was not difficult for members of Congress to envision the National Bureau of Standards fulfilling the role of such a "designated entity," given the well-earned and well-known bond between the Bureau and the technology sector of American industry.

What's in a Name?

Besides wanting a Federal champion for American industry, it is likely that certain members of Congress also recalled the words of Allen Astin, testifying before a House Appropriations subcommittee in 1971:[5]

> Part of the difficulty in some of the lack of appreciation of the range of the Bureau programs and services is the name—The National Bureau of Standards. Some Secretaries of Commerce, on learning of the scope and importance of the

[3] See, for example, the description of "stagflation" by James MacGregor Burns, "The Crosswinds of Freedom," (New York: Vintage Books, 1990) pp. 557-559.

[4] "The technological dimensions of international competitiveness," *National Academy of Engineering*, Washington, DC, April 1988.

[5] See Oversight Hearings Testimony, Chapt. 2.

Bureau activities, have suggested that we devise a new and more descriptive name. I have viewed such suggestions with mixed thoughts. I can definitely see several advantages to a broader name. On the other hand, the present name is held in high regard by the Bureau's specialized clients and there is danger of losing some of this with a new name. I would want to retain the word "standards" in any new title. However, our counterpart laboratories in England and Germany have the names National Physical Laboratory and Physikalisch-Technische Bundesanstalt, respectively, and the word "standards" does not appear.

The National Bureau of Standards had never been represented by a more devoted champion than Allen Astin. Yet it was clear that Astin himself had considered its name to be a mixed blessing. On the one hand, it provided a well-known mark of excellence in research and rigor in objectivity. On the other, it offered a delimiting title that identified only part of the multi-faceted entity that was the Bureau.

"New Activities in Technology"

In tracking the path of Congress towards its designation of NBS for a key role in improving America's position in international competition, it is also well to remember the words of Lewis Branscomb. Branscomb, during his brief but intense tenure as NBS Director, saw Bureau involvement in industrial technology as neither new nor frightening. In his first address to the NBS staff, Branscomb noted the plethora of new responsibilities given NBS by the Congress, many of them ranging far beyond traditional research on measurements and scientific standards. But he urged the staff not to shrink from assigned tasks in applied science:[6]

> I have been aware of the widespread view that the new activities in technology introduce an alien, and some would say incompatible, dimension into NBS—a set of programs essentially different in character from those that have gone before. But the more I look into the problem of fostering innovation—or, if you prefer, encouraging engineering creativity in the solution of practical problems —the more I find that the cure calls for the science of measurement once again, and often at a high level of sophistication.

Branscomb backed up his words with action throughout his short reign, modifying even the style in which NBS programs were presented to Congress during budget hearings. From a listing that emphasized scientific disciplines, Branscomb changed the description to one that portrayed NBS as an agency that addressed national problems:[7]

- Providing the basis for the Nation's physical measurement system.
- Providing scientific and technological services for industry and government.
- Providing the technical basis for equity in trade.

[6] See Assessing Branscomb's Directorship, Chapt. 2.

[7] Budget hearings, *House Subcommittee on Departments of State, Justice, and Commerce, the Judiciary, and Related Agencies,* 92nd Congress, First Session, April 20, 1971, p. 1118.

- Providing technical services to promote public safety.
- Providing technical information services.
- Providing one-of-a-kind facilities for use by NBS and visiting scientists.

It is worth noting that Congress responded favorably to Branscomb's activist language, voting to raise the NBS appropriation by some 30 % for Fiscal Year 1972.

"Industrial Innovation and Productivity"

Early in his tenure as director, Ernest Ambler developed the view that NBS could prosper as a more active partner in American industrial progress. Observing the positive response to Bureau research in the areas of energy, environment, safety, and health, Ambler noted in 1980 the "needs for improved industrial innovation and productivity."[8] Throughout his term, he continually pressed the idea that NBS should become more directly involved with industry in solving technological problems.

Ambler took to heart suggestions in the 1982 Packard Report calling for a sharper definition of agency mission and for closer ties to outside organizations. Under his leadership, Bureau relations with industry expanded vigorously.

"Automated Manufacturing" Shows the Way

The success of the Automated Manufacturing Research Facility might have convinced the last skeptics that NBS could work directly with industrial engineers to enhance their use of technology.[9]

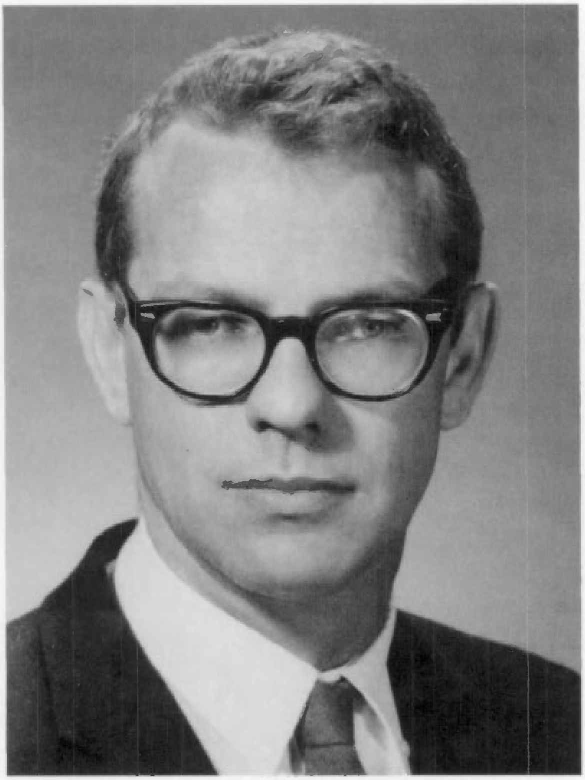
The basis for the Bureau's automated manufacturing project was research in dimensional metrology under the leadership of John A. Simpson and Robert J. Hocken. Taking as one challenge the accurate measurement of large container volumes, Hocken, Simpson, Bruce R. Borchardt, John W. Lazar, Charles P. Reeve, and Philip G. Stein by 1977 had developed new methods for accurate measurements in three dimensions. Their work was based on the use of a classical measuring machine fitted with laser interferometers. The machine and the interferometers were controlled by a dedicated minicomputer to determine the position of a single reference point, from which a machine-independent set of measurements could be created.[10] By 1979, Hocken and Borchardt had evaluated axis non-orthogonality errors associated with the technique.[11]

[8] E. Ambler, Preface to "*NBS 1980*," *NBS Special Publication 600,* January 1981, 40 pp.

[9] Much of the information in this section was kindly supplied by Dennis A. Swyt. See also *The Beginning of "Technology Transfer,"* Chapt. 4.

[10] R. Hocken, J. A. Simpson, B. Borchardt, J. Lazar, C. Reeve, and P. Stein, "Three dimensional metrology," *Ann. Int. Inst. Prod. Eng. Res.* **26**, No. 2, 403-408 (1977).

[11] R. J. Hocken and B. R. Borchardt, "On characterizing measuring machine geometry," *NBSIR 79-1752,* June 1979, 25 pp.



John A. Simpson, an expert in electron physics, worked at NBS/NIST from 1948 to 1993. He received many awards for the excellence of his scientific studies and his management achievements. His vision was of the greatest importance to the creation of the Automated Manufacturing Research Facility.

Within another 2 years, a group including Hocken, Borchardt, Reeve, William C. Haight, Clarence L. Carroll, Ronald G. Hartsock, Fredric E. Scire, and Ralph C. Veale had demonstrated the ability to measure the capacity of ship cargo tanks designed for the transport of liquefied natural gas (LNG) with an uncertainty of only +0.05 % of the total volume. They measured 18 such tanks using the laser-based dimensional metrology, providing calibration reports that specified the tank volumes as functions of their liquid levels.[12]

The measurements presented a challenging problem: each tank held about 5 million gallons of LNG; each tank was made from 10 flat planes which—when assembled—could enclose an eight-story building; and the temperature of the tanks in use dropped to −160 °C, engendering significant volume changes as a result of thermal expansion. The actual volume of the tanks was a critical issue in the pricing of LNG shipments, since no accurate cryogenic flowmeter then existed.

[12] W. C. Haight, R. J. Hocken, B. R. Borchardt, C. L. Carroll, R. G. Hartsock, C. P. Reeve, F. E. Scire, and R. C. Veale, "Estimated accuracy of calibration of some membrane-type LNG transport tanks," *NBSIR 80-2141* January 1981, 83 pp. See also Robert J. Hocken and Philip Nanzetta, "Dimensional metrology at the National Bureau of Standards," *The Physics Teacher* **21**, No. 8, 506-513 (1983).

In 1978, NBS scientist Robert J. Hocken explained the NBS three-dimensional measuring machine to a group of visitors from the National Science Foundation (NSF). From left to right were NBS Director Ernest Ambler, NSF Senior Science Associate Robert Rabin, NSF Director Richard C. Atkinson, Robert J. Hocken, and NSF Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences John B. Slaughter.

The group, then part of the Automated Production Technology Division, also developed methods for the accurate positioning of a numerically controlled milling machine, transforming it into a three-dimensional coordinate-measuring machine by replacing the cutting tool with a sensing probe. Again, the Bureau team broke new ground in the measurement technique, defining and minimizing positional errors endemic to the machine—one of which, for example, resulted from thermal expansion of its parts.

Because accurate measurements directly affected industry's "bottom line," the new Bureau capability was immediately recognized by major portions of America's manufacturing industry as extremely valuable.

John Simpson, Robert Hocken, and William Haight shared the NBS Applied Research Award in 1980 for the development and implementation of the automated, self-correcting, three-axis coordinate-measuring machine.

By 1983, the dimensional-metrology effort had become a mainstay of an Automated Manufacturing Research Facility at NBS. M. J. Mitchell and Edward J. Barkmeyer, Jr. described one of its outstanding problems—the development of a dictionary system for use in integrating existing databases into control processes.[13]

[13] M. J. Mitchell and E. J. Barkmeyer, "Data distribution in the NBS Automated Manufacturing Research Facility," *Proc IPAD II, Advances in Distributed Data Base Management for CAD/CAM, Denver, Colorado, 17-19 April, 1984*, pp. 211-227.

A natural collaboration between researchers working on dimensional metrology and a robotics team from the Institute for Computer Sciences and Technology was fostered by the NBS reorganization of 1978.

James S. Albus, an electrical engineer who left the National Aeronautics and Space Administration in 1973 to study sensors and computer control technology at NBS, led a team that created a variety of robotic devices at the Bureau. These found uses in many military and industrial settings. In one project, NBS prepared specifications for the Navy to use in competitive procurement of robots.

Led by Albus and including Anthony J. Barbera, Mary L. Fitzgerald, and Marilyn Nashman, the NBS robotics team focused its early efforts on some eight features of robots:[14]

- Accuracy of position.
- Dynamics of manipulation.
- Sensors.
- Control systems.
- World modeling.
- Development of software.
- Standards for interfaces.
- Mobility.

The idea to create an Automated Manufacturing Research Laboratory was born in 1979 as NBS scientists realized the significance to American industry of a factory in which every part could be made automatically, with no rejects and little scrap. The concept had several components: careful analysis of the manufacturing process to reduce errors in materials treatment to acceptable levels; generation of manufacturing protocols involving robotics and humans within a generic system; and development of interfacing methods to permit the use of optimum efficiency in the choice of equipment, control computers, and software.[15]

The AMRF received congressional funding as a new NBS initiative in 1981, and it received financial support from a U.S. Navy program in Manufacturing Technology at the same time. Taken together, these funds allowed construction of the facility as an adjunct to the NBS Instrument Shop.

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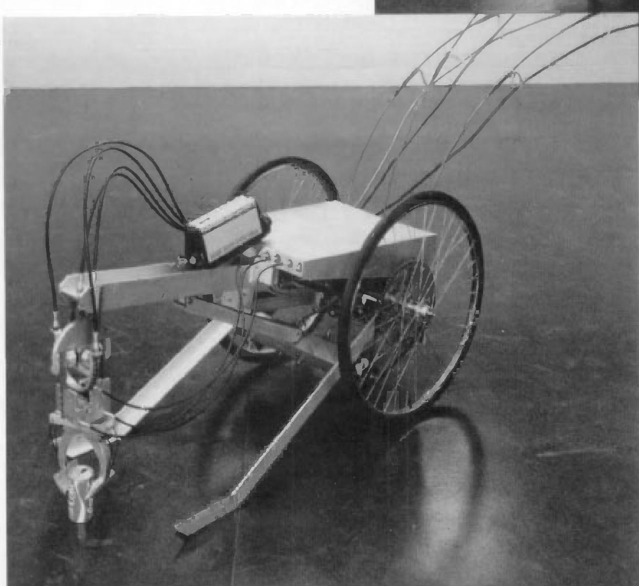
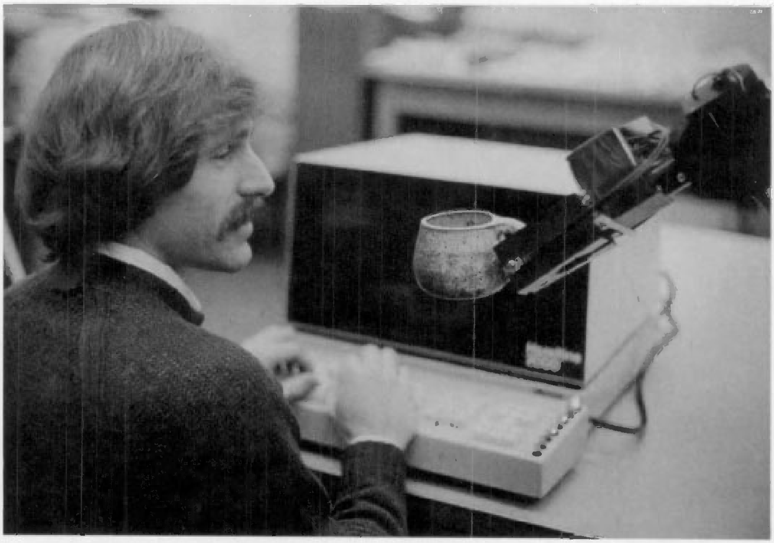
[14] James S. Albus, "Industrial robot technology and productivity improvement," *Exploratory Workshop on the Social Impacts of Robots: Summary and Issues*, February 1982, pp. 62-89. See also J. S. Albus, A. J. Barbera, M. L. Fitzgerald, and M. Nashman, "Sensory interactive robots," *Ann. CIRP* **30**, No. 2, pp. 559-562 (1981).

[15] J. A. Simpson, R. J. Hocken, and J. S. Albus, "The Automated Manufacturing Research Facility of the National Bureau of Standards," *J. Manufacturing Systems* **1**, pp. 17-31 (1982). See also John A. Simpson, "Mechanical measurement and manufacturing," *Control and Dynamic Systems* **45**, pp. 17-30, 1991. See also Philip Nanzetta, "Technology transfer from the Automated Manufacturing Research Program at the National Bureau of Standards," *ibid* pp. 307-331, 1991.



James S. Albus (right) utilized a low-cost, mobile robot (left) to pick up a small object. The robot was built circa 1974 by NBS for the Department of the Navy to prove the feasibility of using low-cost, readily available components in robot construction.



In 1977, a computer-controlled manipulator, used in research that developed sensor control systems for industrial robots, handed NBS electronics engineer Anthony J. Barbera a cup of tea.

Within a few years, the facility had achieved spectacular success. More than 40 companies had sent Industrial Research Associates to work on its projects, and equipment worth more than $12 million had been donated or lent by participating organizations. By the time NBS became NIST, the facility boasted a horizontal turning center, a vertical turning center, a cleaning and deburring center, and a final inspection center. Each center was served by a robot, robotic materials transport, and an automated storage and retrieval system. A *Hierarchical Control System,* developed in concert with hundreds of private companies and other government agencies, operated the facility's equipment.

The AMRF was an operating model of technology transfer, industrial productivity, and industrial competitiveness. Its projects benefitted the U.S. military effort in many ways as well.

So it was that one could easily find reasons for inclusion of NBS in Public Law 100-418, legislation intended to rescue American industry from the ravages of foreign competition. Congress readily saw the Bureau as an effective weapon to be used in the battle. And if its name were to be changed to emphasize its expanded role in the fight, well, Astin himself had not discouraged such a step.

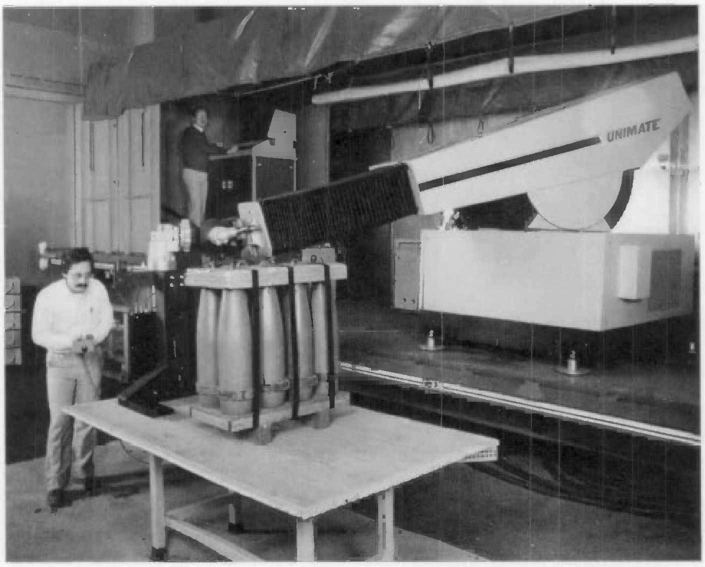
NBS engineering technician Michael Huff (seated) and project manager Kang Lee monitored the Mare Island Flexible Workstation at the Bureau's Automated Manufacturing Research Facility (AMRF). This workstation was developed by NBS for the U.S. Navy's Mare Island Naval Shipyard in the first large-scale transfer of flexible automation technology from the AMRF to a production facility.

PLANNING FOR CHANGE

Most aware of all the Bureau staff regarding impending changes in the NBS charter were three of its leading managers in 1987—Director Ambler and two of his major laboratory directors, Donald R. Johnson, director of the National Measurement Laboratory and John W. Lyons, director of the National Engineering Laboratory. By the time PL 100-418 became law, Johnson had been involved for nearly a year in the extensive planning necessary to prepare the massive text, and Lyons had been involved even longer, though unofficially.

On September 30, 1987, Director Ambler sent to Johnson a memo assigning him to lead the planning effort for the Technology Competitiveness Act:[16]

[16] Memo, "Preparing for the Technology Competitiveness Act Assignments," Ernest Ambler to Donald R. Johnson, September 30, 1987.



In 1985, NBS engineers Azizollah Abrishamian (foreground) and Roger Kilmer began examination of a laboratory testbed for robotic sensor/controllers. The installation was built to study logistics for a U.S. Army human engineering project. The scientists sought to integrate proximity, vision, and other sensors into the NBS-developed real-time robot control system.

In the days just before the unveiling of the NBS Automated Manufacturing Research Facility in November 1983, (left to right) Anthony J. Barbera, Mary Lynn Fitzgerald, Len Haynes, Steve Leake, and Kathleen Strouse worked to solve last-minute problems with the facility's control systems.

> It seems prudent to commit ourselves to a full planning effort in order to prepare for the assignments to the Bureau contained in the House and Senate drafts of the Technology Competitiveness Act.
>
> Effective October 6, 1987, I would like for you to head the planning effort on a full-time basis. While you are on detail from your present assignment as Director of the National Measurement Laboratory, Dr. Helmut Hellwig will act for you.
>
> In addition to leading the planning effort, you will take primary responsibility for working with all the interested parties external to the Bureau. Ray Kammer will assist you in assuming these responsibilities.

Johnson's planning assignment lasted until the following June. During that time he led the effort that resulted in a workable plan for an *Advanced Technology Program, Regional Centers for the Transfer of Manufacturing Technology, State Technology Extension Services, a Non-Energy-Related Inventions* project, and—perhaps of necessity—a change in the venerable name of the National Bureau of Standards. It was a busy time for the manager, but one that he recalled as challenging.[17]

Even before Donald Johnson was operating as the Bureau's designated planner for PL 100-418, John Lyons was involved in discussions with staff members of the Senate Committee on Commerce, Science, and Transportation.[18] Lyons was sought out for his views because Bureau programs such as the Automated Manufacturing Research Facility were located within the National Engineering Laboratory (NEL). Director Ambler encouraged Lyons to provide members of Congress and their staffs with information on the successes of industrially oriented NEL programs. Lyons also provided information obtained by him during visits to "technology centers" in Japan. These were governmental bodies that funded selected industrial research and development initiatives in Japan.

It was the opinion of Lyons that the accomplishments and future plans for the AMRF figured heavily in the eventual "technology transfer" content of PL 100-418.

For both Johnson and Lyons, the new legislation simply reflected a crystallization in Congress of long-felt needs to find some way to stanch the hemorrhage of dollars from a disastrously negative U.S. balance of payments. Lyons—a veteran of two decades of employment in industry—was particularly attuned to reorganization as a frequent response by corporate management to changing conditions. He saw the Congress as a sort of "Board of Directors" for government agencies; unwieldy because of numbers and variation in views held by individual members, but all-powerful nonetheless.[19]

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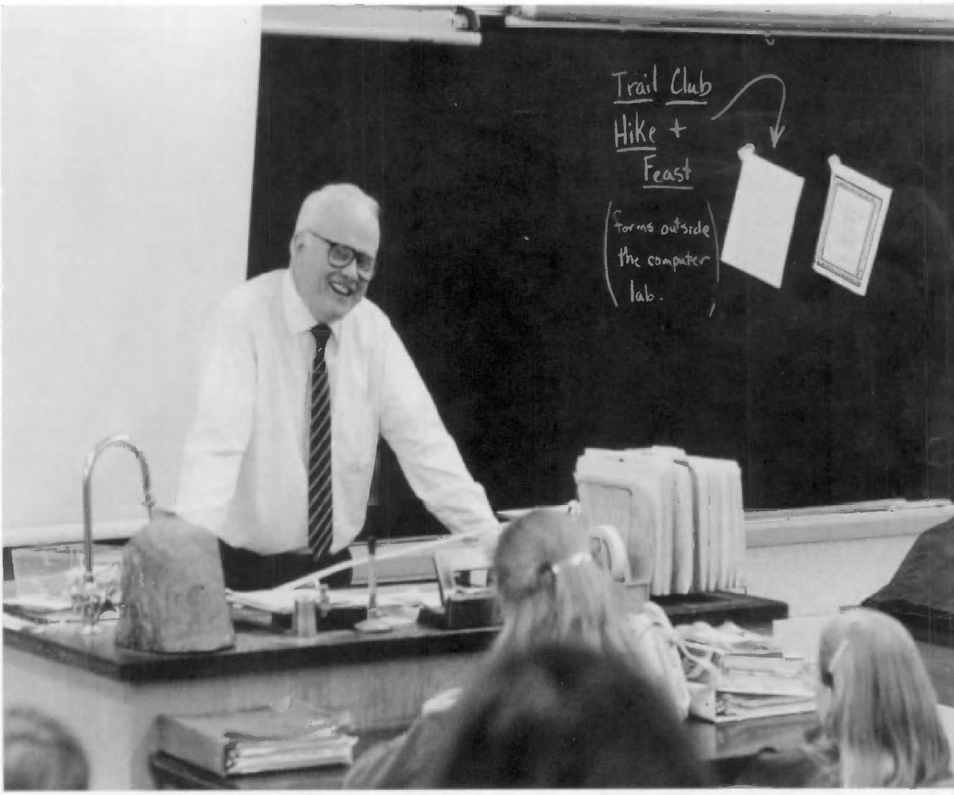
[17] Donald R. Johnson, Oral History, September 8, 1998.

[18] John W. Lyons, Oral History, June 1, 1993, and June 9, 1993.

[19] John W. Lyons, Oral History, June 1, 1993.

In 1987, Donald R. Johnson (right), director of the NBS National Measurement Laboratory, showed Maryland Senator Paul Sarbanes (center) and a member of Sarbanes' staff several examples of NBS Standard Reference Materials.



In February 1991, John W. Lyons taught classes at a Gaithersburg, Maryland, school as part of an annual National Engineers Week "teach-in."

Public Law 100-418

The *Omnibus Trade and Competitiveness Act* received a sympathetic hearing by the 100th Congress, primarily because control of the Congress had passed to the Democratic Party in the 1986 elections. In the minority during the previous years of President Reagan's administration, Senator Hollings and his colleagues on the Commerce, Science, and Transportation Committee favored governmental intervention in the plight of America's industry in international trade. Hollings visited the NBS Automated Manufacturing Research Facility (AMRF) during efforts to bring to his home state a new technology center. In the course of that visit, Hollings recognized the significance of the AMRF program for developing and commercializing new technology. He became a leading proponent of an expanded role for NBS in the National competitiveness effort.

Congressional plans to enhance U.S. competitiveness had surfaced in several draft bills over a period of years. Many of these plans were made part of PL 100-418 to add technological strength to the legislation. Although issues involving international trade dominated congressional discussion of the bill, the future of NBS was bound tightly to its technical provisions.

Many Republican members still agreed with the President that less government was better government, but their numbers were dwindling. By the time Congressional Republicans returned to power in 1995, support of PL 100-418 was moot; the value to U.S. industry of the new programs had been well established.

A New Organic Act

The 26 pages of text of PL 100-418 that referred to NBS was identified as the *Technology Competitiveness Act.* This Act-within-an-Act made few substantive changes in the duties assigned to NBS/NIST, but changed drastically the emphasis on those duties and the level of detail with which they were prescribed. Gone was the simplicity of the two-page legislation approved by the 56th Congress in 1901, with its few lines instructing the Bureau to develop and maintain standards, offer calibration services, provide needed data, and solve technical problems. In its place, Congress sent forth an intricate set of instructions that left no doubt of its intent.[20]

The contrast in length between the Bureau's founding legislation and PL 100-418 is so striking as to merit explanation. In simple terms, the difference in detail between the two acts is less surprising when measured against the gradual lengthening of amendments to the 1901 legislation over the better part of a century.

Appendix A lists more than 70 pieces of legislation affecting the National Bureau of Standards during the period 1901-1993. One of these, the *Solar Heating and Cooling Demonstration Act of 1974,* PL 93-409, exemplifies the trend toward more and more lengthy instructions for all agencies with the passage of time. Some eight sections of the Solar Act pertain to NBS. Descriptions of such matters as definitions of solar heating and cooling, development and demonstration of solar systems to be used in residential and commercial buildings, monitoring of projects, and dissemination of information thus produced more text than had been used to establish the Bureau in 1901. Viewed in this light, the length of PL 100-418 is more understandable.

The *Technology Competitiveness Act*—the portion of the Omnibus Trade and Competitiveness Act that created NIST—consisted of Subparts A through F. The headings for these subparts were:

- Subpart A—National Institute of Standards and Technology.
- Subpart B—Technology Extension Activities and Clearinghouse on State and Local Initiatives.
- Subpart C—Advanced Technology Program.
- Subpart D—Technology Reviews.
- Subpart E—Authorization of appropriations.
- Subpart F—Miscellaneous Technology and Commerce Provisions.

In the following paragraphs, we note significant features of each subpart.

[20] The text of *Subtitle B, Part I* is reproduced in full in Appendix A. So is the NBS founding legislation, PL 56-177.

Subpart A—A New Name for NBS

Section 1 of the original organic act (Public Law 56-177, 3 March 1901) consisted of a single sentence: "Be it enacted that the Office of Standard Weights and Measures shall hereafter be known as the National Bureau of Standards." This sentence was replaced in the new legislation by a page of declarations and intentions rooted in the traditional responsibilities for precise measurements and calibrations, but stressing heavily the importance of providing assistance to American industry in acquiring new basic technologies, including automated manufacturing processes.

As noted earlier, most Bureau employees were startled at the change in the name of the institution from the National Bureau of Standards to the National Institute of Standards and Technology. Few were aware that, save for the unfortunate definition of the acronym NIT ("nit, n. —The egg of a louse or other parasitic insect"[21]), the new name might have become National Institutes of Technology, in analogy with the National Institutes of Health, an organization long respected for its effectiveness in advancing the quality of U.S. health care.[22]

New Functions and New Activities

The language of Section 2 of the 1901 Act, a nine-line paragraph describing the functions of NBS, was given much greater detail in 1950 by Public Law 81-619. That act provided the first complete restatement of NBS functions since its founding. Although the legislation was entirely consistent with the original Organic Act, it enumerated in detail some six functions and 19 activities for the Bureau.

The 1988 *Omnibus Trade Act* further expanded Section 2 to three pages in the U.S. Statutes. By placing it first, the Act emphasized the importance of the following task:

> (1) To assist industry in the development of technology and procedures needed to improve quality, to modernize manufacturing processes, to ensure product reliability, manufacturability, functionality, and cost-effectiveness, and to facilitate the more rapid commercialization, especially by small- and medium-sized companies throughout the United States, of products based on new scientific discoveries in fields such as automation, electronics, advanced materials, biotechnology, and optical technologies.

The new text followed the first instruction with more than 30 detailed provisions that were mostly consistent with ongoing Bureau projects.

In the 1901 legislation, the Bureau had been instructed to exercise its functions for the benefit of "firms and corporations." Within the limits of then-current antitrust legislation, NBS scientists had often followed that instruction, assisting industry in solving its measurements and standards problems. In the new legislation, relations between NIST and industrial firms were spelled out in considerable detail to make it clear that the old antitrust fears limiting contact between NBS researchers and industrial researchers were to be eased considerably.

[21] Webster's New International Dictionary, 2nd Ed.

[22] John W. Lyons, Oral History, June 9, 1993.

NIST Director's Organization Plan

Subpart A also required the NIST Director, within 120 days, to present to the House Committee on Science, Space, and Technology and the Senate Committee on Commerce, Science, and Transportation a detailed organization plan for NIST. The plan had to satisfy several requirements:

- Establish the major operating units of NIST.
- Assign each of the required functions of NIST to one or another of these units.
- Provide details of a 2-year program for NIST, including an *Advanced Technology Program.*
- Provide details indicating how NIST would expand and fund a *Non-energy-related Inventions Program.*
- Make no changes in the Center for Building Technology or the Center for Fire Research.

Creating a plan for reorganizing NBS into NIST so quickly was a challenging task, though it was made easier by the preliminary planning carried out by Johnson and Lyons. Foretelling a useful, expanded role for NIST in technology transfer was itself problematic, since only the first steps in that direction had been taken. Forecasting the likely interests of a new presidential administration—to be elected and installed just as the plan was due to be submitted—presented similar uncertainties. Another problem was that Ernest Ambler was about to retire from government service after 14 years as the agency director—he might have felt it wise to leave some or all of the transition decisions to his successor.

As matters would turn out, Ernest Ambler and his deputy director, Raymond G. Kammer, Jr., would share the responsibility for submitting the required organization plan to Congress.

Subpart B—Technology Extension Activities

Technology Extension Activities, the subject of Subpart B of Title V, were created in the image of the extension centers of the Department of Agriculture. The agricultural centers had been powerful forces in disseminating up-to-date information on farming practices throughout America in an earlier time, and they still served U.S. agriculture well in 1988.

Regional Technology Centers

As part of the extension services, PL 100-418 mandated the establishment of Regional Centers for the Transfer of Manufacturing Technology. These centers, to be "affiliated with any United States-based nonprofit institution or organization that applies for and is awarded financial assistance under this section," were intended to become technological resources for U.S. manufacturing companies.

Activities of the new centers were to consist of demonstrating "automated manufacturing systems and other advanced production technologies" to industry, especially the small- and medium-sized firms that could ill afford to send research associates to NIST. Along with relevant information, the centers would be authorized to lend equipment to firms with fewer than 100 employees.

Each Regional Center was to be funded at least 50 % by its sponsoring organization. The maximum duration of support for any center was set at six years.

Authorization for the appropriation of earmarked funds—$40 million for fiscal years 1989 and 1990—was given for the Regional Centers program. However, the size of the program clearly would be determined by the amount of funds actually appropriated for it.

State Technology Programs

In addition to the Regional Centers, the new Act directed NIST to provide technical assistance to individual State technology programs through a variety of other activities.

The assistance was to begin with a national survey—to be completed within 120 days—of technical help currently provided by the states to manufacturing firms within their boundaries. On the basis of the information so acquired, NIST was to suggest ways by which it could make the state extension services more effective.

The legislation specified that information and advice, workshops for state personnel, and cooperative agreements between NIST and individual state governments should be used to implement the NIST activity. Appropriations to support the state extension program were authorized to the extent of $2 million per year over the following 3 fiscal years.

Non-Energy Inventions

Another paragraph of the new legislation directed the establishment of a program for the evaluation of inventions that were not energy-related (the NBS program which evaluated energy-related inventions was not to be impacted by this activity).

Subpart C—Advanced Technology Program

Subpart C of the Technology Competitiveness section of the new act addressed the establishment of an *Advanced Technology Program,* to be created at NIST.

The stated intent of the ATP was to help American businesses to:

- Rapidly commercialize new, economically significant scientific discoveries.
- Refine manufacturing technologies.

The clear motivation of the ATP was to enhance the competitive positions of U.S. manufacturing enterprises. Joint ventures among NIST, universities, and independent research organizations were encouraged, with the transfer of funds to individual companies in support of new, generic technical plans. It was hoped that such a step would "avoid providing undue advantage to specific companies."

The text suggested that joint ventures might consist of start-up funding for demonstration projects involving development and testing of equipment and process prototypes. It also encouraged emphasis on areas of NIST technical strength, and suggested that the collaborations make use of the provisions of the *1980 Stevenson-Wydler Technology Act* where appropriate.

The merit review process was to be used in choosing joint-venture collaborators. Corporate intellectual property was to be protected at all times.

Visiting Committee on Advanced Technology

The statutory Visiting Committee, which had advised the Secretary of Commerce on the state of NBS since its founding, was replaced in the new legislation by a Visiting Committee on Advanced Technology (VCAT). The new entity was to consist of nine members, appointed by the NIST Director. At least five of these were to come from U.S. industry, with the rest coming from academia. No one was to represent the Federal Government. The VCAT was to meet quarterly or more frequently. An annual report was to be transmitted to the Secretary of Commerce with reference to the new responsibilities of NIST.

Subpart D—Technology Reviews

Subpart D placed reporting tasks in the hands of the President. He was required to include in his 1990 budget request statements of policy and budget proposals in four research areas; semiconductors and semiconductor manufacturing technology, fiber optics and optoelectronic technology, superconductivity, and advanced technology for manufacturing. There would be plenty of work for NIST staff members in preparing these reports!

Subpart E—Authorization of Appropriations

The new act authorized about $145 million for technology activities at NIST for Fiscal 1988. The total was distributed among the following activities:

- Measurement Research and Technology, $41.9 M.
- Engineering Measurements and Manufacturing, $40.3 M.
- Materials Science and Engineering, $23.5 M.
- Computer Science and Technology, $7.9 M.
- Research Support, $19.6 M.
- Cold Neutron Facility, $6.5 M.
- Technology Extension Activities, $5 M.

Congressional *appropriations* of funds did not always match congressional *authorizations* (the numbers given above). In Fiscal 1988, for example, the authorization figures given above, totaling just under $145 M, did not materialize in the appropriation, which totaled a bit less than $138 M.[23]

[23] See Appendix I.

Subpart F—Other Provisions

Among provisions discussing, for example, continuity for the agency, user fees, and Stevenson-Wydler Act amendments, Subpart F of the new act contained one page of kind words for the Metric System, designating it as "preferred" for U.S. trade and commerce. Escape clauses were retained, however, in case metric measure was found "economically infeasible," "impractical," or "inefficient." In addition, use of traditional measurement systems was approved for non-business activities. The metric system still was obliged to make its own way through America's technical life.

A New Agency Begins Work

Resistance within the organization to the change in name from NBS to NIST died hard. Many staff members had exerted themselves greatly to ensure that the initials "NBS" on technical work denoted accuracy and objectivity. They were not happy that people who knew little of the organization could eradicate its name. Gradually, however, it became obvious to all that the deed was irreversible. It was time to begin new lives as employees of—could they say it?—NIST.

Ernest Ambler was still director when NIST began its life in August 1988, although he had announced his intention to retire from government service in April 1989. Within 4 months, however, Ambler had acceded to a request by Secretary of Commerce C. William Verity to serve temporarily as Under Secretary for Technology, a post created by Verity to enhance the role of technology in his department.

Along with two smaller agencies, the Under Secretary was responsible only for NIST, so that Ambler was able to participate—albeit at some distance—in the guidance of his home agency while on duty "downtown." Ambler returned to NIST in time to retire as its director.[24]

Raymond G. Kammer, Jr., Acting Director

Ambler's involvement with the office of Under Secretary for Technology left effective leadership of NIST to Deputy Director Raymond G. Kammer, Jr. Kammer, unique among those charged with direction of the agency, had no training as a scientist. His first position with NBS, in 1969, was as an analyst in the Office of Program Planning. In a series of assignments in budget and program analysis both at NBS and Commerce, however, Kammer became familiar with the management of Bureau technical projects. He quickly learned to evaluate the effectiveness of technical work despite his lack of formal training in technology. Ernest Ambler selected Kammer to be his deputy director in 1980. He served in that post until Ambler accepted the temporary position of Under Secretary of Commerce for Technology on December 2, 1988. At that time, Kammer became Acting Director of NIST; there he served until John Lyons was confirmed as Director on February 9, 1990.

[24] Ambler, *Special Publication 825*, pp. 39-40, 1991.

In 1977, NBS Director Ernest Ambler presented NBS senior program analyst Raymond G. Kammer, Jr. (center), with the William A. Jump Memorial Foundation Meritorious Award for Exemplary Achievement in Public Administration. Associate Director for Programs Howard F. Sorrows stood at Kammer's left.

NIST Reorganization Plan

In one of his first acts as NIST director, Ernest Ambler established an *Advanced Technology Program* (ATP). As mandated by PL 100-418, the program was made part of the office of the NIST director. Donald R. Johnson, who helped prepare the legislation describing the new program, was designated Acting Chief of the ATP.[25]

Another of Ambler's early acts as NIST director was to reassure the staff that, although the agency had been given new and ambitious marching orders, it would continue to embody high standards of scientific competence. Ambler accomplished this goal through an interview entitled "NBS has new name, expanded role," prepared by Michael Baum, a NIST Public Affairs Specialist. Discussing the new legislation, Ambler offered a prefatory statement:

> I believe the most significant part of this legislation is found right up front in the list of functions assigned to the agency. We now have a direct, unambiguous charge to work closely with industry on the development and use of the new technologies that U.S. companies need to stay competitive in the world marketplace.

[25] NIST Admin. Bull. 88-13, September 20, 1988.

The interview mentioned the Regional Centers for the Transfer of Manufacturing Technology, the Advanced Technology Program, the Technology Extension Program, and the Non-energy Inventions Program, all embodied in the Trade Act but unfamiliar to most of the NIST staff. While no details were given of the manner in which the new programs would be accomplished, Director Ambler expressed pleasure that Congress had shown faith in the traditional scientific capabilities of the Bureau:

> During the past 87 years as the National Bureau of Standards, this agency developed a reputation, of which we are all quite proud, for the highest standards of technical competence and objectivity. As the National Institute of Standards and Technology, we will continue to maintain the same high standards and to pursue excellence.[26]

In December 1988, Acting Director Kammer submitted to the Department of Commerce a proposed reorganization plan for NIST as required by PL 100-418. In the new plan, the four existing major units of NBS remained intact. This step was intentional. It minimized disruption of continuing programs which, after all, would be expected to provide the bulk of NIST accomplishments for the immediate future.

The most noticeable change from the structure of the old NBS was the addition of a new organizational unit identified as Industrial Technology Services (ITS), with Donald Johnson at its head. Comprising the new ITS were the following units:

- The Manufacturing Technology Program, headed by Philip N. Nanzetta.
- The Advanced Technology Program under George A. Uriano.
- The Office for Standards Services, led by Stanley I. Warshaw.
- The Office for Technology Commercialization, headed by David E. Edgerly.
- The Office for Industrial Extension Services under George P. Lewett.
- The Office for Measurement Services, with no chief named.

In addition to the new components, the reorganization plan included three traditional outreach programs—Standard Reference Materials, Standard Reference Data, and the calibration services—as parts of the Industrial Technology Services unit.

Kammer expected that the new structure might take effect by May 1989.[27]

An Associate Director for Quality Programs

In the context of NIST's mandate for increased emphasis on industrial productivity, the Malcolm Baldrige National Quality Award (see *The Malcolm Baldrige National Quality Award,* Chapt. 4) assumed new significance. First presented in November 1988, the award resonated immediately within American industry. The criteria used in judging award entries, circulated widely among manufacturing firms, seemed to provide both an incentive to excel and a recipe for excellence.

[26] "NIST Research Reports," *Special Publication 743,* October 1988.

[27] NIST Admin. Bull. 88-16, December 14, 1988.

In recognition of the high place deserved by the Baldrige award, Raymond Kammer created the post of Associate Director, NIST, for Quality Programs. Curt Reimann, who had generated the nation-wide program on short notice, was designated to act as director of the new office.

Regional Manufacturing Technology Centers

As directed by the provisions of the Trade Act, Philip Nanzetta, head of the Manufacturing Technology Centers program, quickly prepared and circulated application forms for use in choosing regional centers. Some 36 non-profit organizations applied for the designation despite the short notice.

The first Regional Manufacturing Technology Centers to be established were located at the Cuyahoga Community College in Cleveland (The Cleveland Advanced Manufacturing Program, a not-for-profit organization intended to emphasize research and development, technology applications, and training), Rensselaer Polytechnic Institute (RPI) in Troy, NY, and the University of South Carolina (USC) in Columbia.

At RPI, the funding provided by the program—approximately $1.5 million in matching funds per center—was expected to help establish the Northeast Manufacturing Technology Center, dedicated to applying advanced manufacturing technologies to material removal, assembly, and inspection of mechanical components for the automotive, consumer and electronics industries. The South Carolina Technology Transfer Cooperative, to be established at USC, would involve faculty members from nearby Clemson University to help transfer new manufacturing technology to small- and medium-sized metal-fabricating companies.

Kammer said of the choices, "We expect not only to monitor the progress of these centers but to work closely with them. NIST researchers will visit the centers, and we expect the centers' staffs to spend time at our laboratories."[28]

The major NIST organization expected to interact with the new Regional Centers was the Automated Manufacturing Research Facility (AMRF), known in some circles as the "factory of the future." The AMRF already had developed and implemented new manufacturing techniques in cooperation with industry, government and universities.

New Appointments

As part of the effort to lay a solid foundation for NIST, Acting Director Kammer made several appointments to managerial positions during 1988-89:

- Dennis A. Swyt, an NBS/NIST staff physicist since the early 1970s, was assigned to head the Precision Engineering Division of the Center for Manufacturing Engineering. Swyt was an expert in optical surface and linewidth measurement.

- Richard H. F. Jackson, an applied mathematician, was named deputy director of the Center for Manufacturing Engineering.

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[28] Matt Heyman, "New Centers to Aid Industry," NIST Research Reports, *NIST Special Publication 761*, March 1989, pp. 10-11.

- Hai S. Lew, veteran of earthquake investigations and other structural studies in the Center for Building Technology, was designated chief of its Structures Division. Barry I. Diamondstone, an analytical chemist, was named Deputy Director of the Center for Analytical Chemistry.
- Rance A. Velapoldi, former deputy director of the Center for Analytical Chemistry, was named chief of the Gas and Particulate Science Division.
- Frederick C. Johnson, former chief of the Mathematical Analysis Division, was assigned to the position of associate director of the Center for Computing and Applied Mathematics (CCAM).
- John A. Brown, former head of the Advanced Computing Environment group, was named assistant director for Boulder of the CCAM.
- Patsy B. Saunders was assigned as acting chief of the Information Systems Division in the CCAM.
- Two new divisions were created in the CCAM to replace the Mathematical Analysis and the Scientific Computing divisions. A Scientific Computing Environments Division was formed with Sally E. Howe as chief, and an Applied and Computational Mathematics Division was created with Paul T. Boggs at the helm.
- B. Stephen Carpenter, an expert in nuclear tracer techniques, was selected to head the Office of International Relations.
- J. Michael Rowe, veteran of years of research in solid state physics at the NBS reactor, was named chief of the Reactor Radiation Division.

Settling in at NIST

In June 1989, Kammer spoke before the Senate Committee on Commerce, Science and Transportation about the legislation passed the previous year. His comments included the following remarks:

> This past year has probably been one of the more eventful in our history as we made the transition from the National Bureau of Standards to the National Institute of Standards and Technology. Along with that name change, we saw the enhancement of our traditional measurement research and standards function to include a more general mandate to improve the competitiveness of U.S. industry.
>
> To my way of thinking, the NIST now has three major elements: measurement (providing the scientific data and standards that our economy needs to compete in the world market), technology (assisting U.S. industry to make world-class products), and technology transfer (accelerating the application and wide deployment of new technologies). World-class products have the following characteristics: highest quality, advantageous life-cycle cost, modern features, and prompt availability in the marketplace.

Kammer went on to describe NIST programs that contributed to the success of competitiveness effort. Product quality, he said, was enhanced by the Malcolm Baldrige National Quality Award, created by Congress to promote world-class product manufacture. As noted above, the Malcolm Baldrige Award competition was managed by NIST and quickly established a productive relationship between American industry and NIST in terms of making improved quality an industry goal.[29]

A second example given by Kammer was that of measurement science. The new NIST superconducting volt standard and the NIST scanning electron microscope with polarization analysis both provided world-leading advances to help entire industries to compete better in world markets.

Kammer described the NIST work in intelligent processing as an example of a new technology that could be communicated broadly, and he completed his report by noting the designation of Regional Manufacturing Technology Centers as a new means of technology transfer.

In an article in the newly renamed *Journal of Research of the National Institute of Standards and Technology,* Donald Johnson outlined the new directions that would accompany the transition to NIST, with emphasis on its new responsibilities:[30]

> The rapid loss of competitiveness of American industry in international markets is an extremely serious problem with wide-ranging consequences. Its causes are many, but among them certainly are the slow rate at which new technology is incorporated in commercial products and processes.
>
> As a nation, we have been slow to capitalize on new technology developed from America's own intellectual capability. Our government must now find ways to help companies meet the demand of global competition, when speed is of the utmost importance.
>
> NIST will maintain the traditional functions of NBS in support of U.S. industry and will continue to offer the full array of measurement and quality assurance services including calibration services, standard reference materials, standard reference data, and measurement assurance programs.

A Caution to Congress

The 1988 Visiting Committee on Advanced Technology, replacing the former NBS Visiting Committee upon the enactment of PL 100-418, was chaired by William D. Manly, a consultant to the Oak Ridge National Laboratories. Making up the balance of the committee were Arden L. Bement of TRW Corporation, John G. Bollinger of the University of Wisconsin, Nolen M. Ellison of the Cuyahoga Community College, Jeanette G. Grasselli of Ohio University, William G. Howard of the National Academy

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[29] The award was established by the Malcolm Baldrige National Quality Improvement Act, August 1987. For a brief note on its early success, see John Makulowich, "Quest for Quality," NIST Research Reports, *NIST Special Publication 761,* March 1989, pp. 16-18.

[30] Donald R. Johnson, "New program and directions at the National Institute of Standards and Technology," *J. Res. NIST* **95**, No. 1, pp. 1-5 (1990).

of Engineering, John P. McTague of Ford Motor Company, William P. Schlichter of AT&T Bell Laboratories (retired), and William J. Spencer of Xerox Corporation. This group, representing considerable technical experience and a variety of viewpoints on science and technology, had strong words for the Secretary of Commerce and the Congress on the need for adequate resources for the new NIST:

> The Administration and Congress must work together to make Federal funding of civilian technology development a high priority. The Committee encourages the Federal Government to provide the resources NIST needs for real growth and for fulfilling its mandate under the Trade Act to provide leadership in developing technology that meets national needs. These resources are not now available. In fact, a shortfall in the 1989 NIST budget threatens the health of an agency that has just been given a lead role in promoting U.S. technological competitiveness. This will be interpreted as a lack of commitment by the Federal Government to continued U.S. leadership in science, technology, and international economic competition.

The committee report called attention to the potential damage to NIST programs from consistent underfunding of the agency. Key technical personnel left NIST during the previous year, noted the report, and more losses could be expected if support for research programs was not forthcoming. The committee went on to point out that $40 million was authorized for the Regional Centers for the Transfer of Manufacturing Technology for the 2-year period 1989-90, but only $7.5 million was actually appropriated for Fiscal 1989 to get the program going. Furthermore, no funding at all had been proposed for the centers in the 1990 budget.

In its 1989 report, the same committee observed that funding for NIST core science and engineering had failed to even keep up with inflation. In addition, no new work proposed in the 1990 budget was funded. The only alternative to dropping needed research at NIST was to seek financial support from other government agencies, a poor strategy in the best of times.

A caution sounded 10 years later in an editorial by Peggie J. Hollingsworth, president of Sigma Xi, The Scientific Research Society, eerily echoed NIST's situation in 1989. Hollingsworth warned that a trend to university-based "Technology Transfer"—the commercialization of research results—held danger in two areas for the scientific enterprise. First, the effort to create new wealth for the university through the commercialization of applied projects might well sap the energy—formerly given by the faculty to undirected research—that was essential for the transformation of students into imaginative scientists and engineers. Second, the traditional openness of academic scholarship might well suffer as faculty members suppressed publication of results until patent or other commercialization issues were resolved.[31] It was not difficult to see in Hollingsworth's words a warning that NIST's ability to preserve its scientific competence might suffer from an overemphasis on technology transfer.

[31] P. J. Hollingsworth, "Technology Transfer in Higher Education," *American Scientist* **87**, p. 482, 1999.

CHAPTER SIX

METROLOGY MAKES ROOM FOR INDUSTRIAL PRODUCTIVITY (February 1990–April 1993).

With the change in name reinforcing—on a continual, daily basis—a change in the way that the former National Bureau of Standards was perceived both within and outside the venerable institution, it fell to new leadership to define the myriad of details by which traditional metrology would co-exist with expanded efforts to boost U.S. industrial productivity.

The new legislation made clear that NIST should maintain its historical role as the U.S. authority on standards of measurement. Yet the same legislation called explicitly for emphasis on programs meant for the rescue of American industry in the international economic arena. Managing the balance between these sometimes conflicting goals fell to John Lyons and his senior management staff.

By the time Lyons completed his 3-year term as director, the new orthodoxy of industrial productivity had replaced the standards-and-science orientation of the old National Bureau of Standards. Only time would tell whether the dual roles could co-exist in the same unique institution.

GEORGE HERBERT WALKER BUSH

George Bush was a man of many accomplishments and a Washington insider since 1966. The son of Senator Prescott Bush of Connecticut, George was a decorated Navy pilot in World War II and a graduate of Yale University in 1948. He was an oil-company executive for several years prior to his election to the U.S. House of Representatives in 1966 and 1968, representing Houston, Texas. He was appointed by President Nixon to be Ambassador to the United Nations in 1971 and served as Chairman of the Republican National Committee during Watergate. President Ford posted him as chief of the U.S. Liaison Office in Peking in 1974, and as Director of the Central Intelligence Agency in 1976.

In 1980, Ronald Reagan chose Bush as his Vice-Presidential running mate. Their Republican ticket handily beat the Democratic team of President Jimmy Carter and Vice President Walter F. Mondale, winning 489 of the 537 available electoral votes. The Reagan-Bush ticket won again in 1984, defeating Walter Mondale and Geraldine Ferraro by an even larger margin.

Bush was effective as Reagan's Vice-President, leading the administration's battles on regulatory reform and an anti-drug campaign, assisting the President with crisis management, and serving well as Reagan's surrogate when the President was shot by John Hinckley.

Running for President on his own in 1988, Bush chose Danforth Quayle as his candidate for Vice-President. They faced Michael S. Dukakis of Massachusetts and Lloyd Bentsen of Texas in a campaign nearly devoid of issues save those of personality. The voter turnout on election day fell to 50 % of eligible voters—the lowest in more than 60 years. However, the Bush-Quayle ticket still won easily.

One of Bush's early tasks was to nominate a permanent director of the National Institute of Standards and Technology. This he did, on November 17, 1989; he nominated John W. Lyons, a career scientist and at that time the director of the NIST National Engineering Laboratory.[1]

During his term as America's 41st president, Bush saw the end of the Evil Empire—the Berlin Wall was breached in 1989, and the Union of Soviet Socialist Republics collapsed in 1991 into a loose federation of tentative democracies. The Reagan-Bush policy of militant anti-communism contributed heavily to the termination of the Cold War; Bush gladly undertook the construction of a suitable U.S. stance with respect to post-Cold-War Eastern Europe.

Bush directed the U.S. participation in the Persian Gulf War in early 1991 that successfully liberated Kuwait, overrun by the Iraq military during 1990. Although the U.N. forces stopped short of total victory, the United States, and thus its President, stood tall as the defender of militarily weak nations.

Although he basked in the glory of America's armed might, Bush was required to face the punishing trade and budget deficits that he inherited from his predecessor. He found it increasingly tricky to reduce the deficits while struggling with military cutbacks mandated by the end of the Cold War. His efforts brought on a recession and rising unemployment that persisted throughout his term of office. Bush also presided over the resolution of a financial scandal arising from the insolvency of a number of profligate savings and loan institutions; rescue of the defunct businesses cost the U.S. treasury more than $100 billion.

President Bush chose Robert A. Mosbacher, Sr., a flamboyant Texas oilman, to be Secretary of Commerce in 1988. In 1992, while Bush was campaigning for re-election, he replaced Mosbacher with Barbara H. Franklin, former Commissioner of the Consumer Product Safety Commission (1972-78) and more recently (1979-88) Senior Fellow of the Wharton School of Business at the University of Pennsylvania.

William J. Clinton, Governor of Arkansas, successfully gained the presidential nomination of the Democratic party in 1992. With Albert Gore, Jr. as his running mate, Clinton attacked the Bush-Quayle economic policies vigorously. H. Ross Perot, an independent candidate for President, added spice to an already heated campaign. In an election that attracted the highest voter participation since 1968, the Clinton-Gore team defeated both the Bush-Quayle slate and the Perot-Stockdale ticket.

Clinton's election, preventing a second term for George Bush, would also spell the end of John Lyons' tenure as NIST director.

[1] "Weekly Compilation of Presidential Documents," 25, p. 1774, 1989.

JOHN WINSHIP LYONS

If there was one NIST manager who was at ease with the change of name and modification of purpose as stated in the 1988 revision of the NBS Organic Act, that manager was John Lyons, nominated by President George Bush on November 17, 1989, to be the ninth Director of the agency newly re-named the National Institute of Standards and Technology. Lyons was employed for 20 years by the Monsanto Corporation before joining the staff of NBS in 1973. There he had seen re-organizations, technical re-alignments, and changes in corporate goals on many occasions. He expressed his views on the changes wrought by Public Law 100-418 plainly:

> The Bureau is whatever the Congress says it is. Congress is the Board of Directors and what they say, by definition that is what you are.[2]

Lyons was raised in Boston and graduated from Harvard College with a A.B. degree in chemistry. After 2 years of service in the U.S. Army, he joined the Monsanto Corporation as a chemist. During his service with Monsanto, he obtained M.A. and Ph.D. degrees in physical chemistry from Washington University in St. Louis. While at Monsanto, Lyons investigated the chemistry of phosphorus compounds, the behavior of polyelectrolytes in solution, and rheology.

Participation on an evaluation panel for the NBS fire program led to his joining NBS in October 1973 to head the program.[3] During that year, a report entitled *America Burning,* issued by the National Commission on Fire Prevention, awakened the country to America's deplorable fire-safety record. The United States suffered the highest death rate from fire among all industrial nations, and the worst property-loss rate, too. Spurred by the impact of the report, the 93rd Congress enacted the *Federal Fire Prevention and Control Act of 1974*; it mandated, among other things, the creation of a Center for Fire Research at NBS. Lyons became the first director of the new center.[4]

During the NBS reorganization of 1977-78, Director Ernest Ambler selected Lyons to lead the planning of a new entity, a National Engineering Laboratory, and then to become its first director. The NEL included centers for applied mathematics, electronics and electrical engineering, mechanical engineering and process technology, building technology, fire research, and consumer products. Lyons spent more than a decade working with Ambler and the NEL managers to complete an organization—eventually including a separate chemical engineering unit—that could interact with American industry in all the engineering areas.[5] His leadership in the NBS fire program and in the creation and management of NEL earned him election in the National Academy of Engineering. Ultimately, Lyons was entirely at ease with the idea that NBS could provide direct assistance to bolster U.S. industry in its efforts to adopt the most modern methods of manufacturing.

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[2] John Lyons, Oral History, June 1, 1993.

[3] NBS Admin. Bull. 73-70, October 29, 1973.

[4] See Chapt. 3, The Bureau Gets a New Fire Law and a New Fire Center.

[5] Lyons, Oral History, June 1, 1993.

John W. Lyons was the ninth director of NBS/NIST.

Aware in 1988 that Ernest Ambler intended to retire within months, Lyons hoped to succeed him. A decade of management experience in the engineering/technology area of NBS provided Lyons with a background that matched well the emphasis on technology transfer sought by congressional authors of the 1988 Trade Act.[6]

As noted above, President Bush nominated Lyons for director on November 17, 1989. During his confirmation hearing in February 1990, he was asked about his view of the future for NIST. His response was optimistic:

> In some critical aspects the Institute will be unchanged in the years ahead. We shall still have a substantial core of fundamental research in science and engineering and thereby serve both our internal interests and those of the technical community at large. We shall continue our dedication to excellence in all of our activities. We shall continue to work on the basic physical and chemical standards of measurement on which our National quality assurance systems are based and provide the necessary services to all those seeking to base their work on ours. The Institute will keep up its work in supporting technologies. We shall continue to serve as a crossroads for the technical community, conducting hundreds of conferences, hosting thousands of visitors, and participating in a myriad of external committees and activities. The Institute will remain an open laboratory.

[6] John Lyons, Oral History, June 9, 1993.

The U.S. Senate confirmed the nomination on February 8, 1990.[7] The next day, John Lyons took office as the ninth Director of NBS/NIST.[8]

During his swearing in ceremony, held March 20, 1990, Lyons gave the following view of NIST:

> I am the ninth Director of this great laboratory, the second chemist, and perhaps the first technologist. I am only the second director to have had extensive work experience in industry. Our first priority here at the National Institute of Standards and Technology is to provide technical support to industry. This priority is written down in law. It is also in direct support of Secretary Mosbacher's top priority for the Department of Commerce: namely, to support industry's efforts to improve competitiveness in the global marketplace.
>
> I have enunciated two other top priorities: to support selected programs in public health and safety and to support the scientific and engineering research communities through a program of fundamental research.
>
> There are three related aspects of NIST that are critical to achieving success with the three priorities I have just mentioned. These are excellence, strength of our research base, and relating our rate of growth to industrial demand.
>
> Excellence—our reputation for getting it right and getting it right the first time—is our stock in trade. We must not sacrifice this reputation for any objective. Our research base is the foundation on which we build our applied programs and to which we recruit our next generation of staff. It is essential that this research base be maintained at substantial fraction of the total effort and that it do world-class work.
>
> And finally, we must find a way to relate the rate of growth of NIST to that of the industries we serve. These industries are based on advanced technologies that are ever more complex. We find we have to provide more and more services to them. Finding the resources to respond to these needs is a challenge we must somehow meet.

Taking Charge

John Lyons had the same kind of head start on the task of directing the work of NIST that all previous directors save two had enjoyed—he had spent more than a decade as an NBS employee. In addition, his participation in the planning of the 1988 Trade Act gave him a deep understanding of the intentions of Congress for the newly re-created agency.

In testimony during the 1991 Congressional appropriations hearings, Lyons reviewed the agency's progress since NBS became NIST:

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[7] "Lyons New Head of NIST," NIST Research Reports, *NIST Special Publication 783*, May 1990, pp. 5-8.

[8] John W. Lyons, "Welcome and Current View," in *NBS/NIST, A Historical Perspective: A Symposium in Celebration of NIST's Ninetieth Anniversary, March 4, 1991*, Karma A. Beal, Editor, *NIST Special Publication 825*, April 1992, p. 2.

The Omnibus Trade and Competitiveness Act of 1988 established new programs and approaches on a successful foundation at the old National Bureau of Standards. The Act confirms the importance of the existing NBS functions and reaffirms the primary NBS mission to promote the competitiveness of U.S. industry.

Today NIST is a far different laboratory. Over a thousand guest scientists and 88 cooperative research and development agreements with industry and academia (plus 33 in the process of completion) have become part of our lives. We are in the closing stages of our first competition under the Advanced Technology Program. We have three Regional Centers for the Transfer of Manufacturing Technology in the Manufacturing Extension Partnership Program, and we are in the process of selecting two more.

Restructuring NIST

Lyons began to adapt the management of NIST to his vision for the agency as soon as he was nominated as Director.[9] He formed task groups for the purpose of replacing the National Measurement Laboratory and National Engineering Laboratory hierarchies with a management structure that could better focus on newly assigned goals. Despite his early start, however, the new structure did not gain final approval from its many overseers—the Department of Commerce, the Office of Management and Budget, and four congressional committees—until February 1991. In the meantime, many managers were "designated to serve" in their newly assigned positions.

An interim organizational chart issued in July 1990 and a more complete one issued in March 1991 (the latter is shown in part in Appendix K) defined the new structure of NIST. Raymond Kammer continued as Deputy Director until his departure late in 1991 to accept a position as Deputy Under Secretary of Commerce for Oceans and Atmosphere—the chief operating officer for the National Oceanic and Atmospheric Administration. Lyons appointed Samuel Kramer, his long-time planning assistant in the National Engineering Laboratory, to the post of Associate Director of NIST; upon the departure of Deputy Director Kammer, Lyons designated Kramer as Kammer's replacement. Apart from Kramer, the new structure had no Associate Directors.

In accordance with the wishes of Congress, Lyons placed two of NIST's newest entities—the Office of Quality Programs, headed by Curt Reimann, and an Advanced Technology Program (APT), headed initially by Donald R. Johnson, directly under his own supervision. Within a few months Lyons appointed George A. Uriano, a physicist with more than 26 years of service at NBS, to be permanent head of the ATP. It fell to Uriano to manage the large transferred-funds program to develop—on a cost-sharing basis—a variety of high-risk, innovative technologies to enhance the economic growth of American industry.

Within the ATP was created an important unit that contained most of its in-house competence—the directorate of Technology Services, led by Donald R. Johnson. It contained an Office of Standards Services, under Stanley I. Warshaw; an Office of

[9] John Lyons, Oral History, June 9, 1993.

Technology Commercialization, headed by Cary Gravatt; an Office of Measurement Services, under Stanley D. Rasberry; an Office of Technology Evaluation, under George P. Lewett; and an Office of Information Services, headed by Patricia W. Berger.

A directorate of Administration, led by Guy W. Chamberlain, Jr., included a Management and Organization Division, headed by Sharon E. Bisco; an Office of the Comptroller, under John C. McGuffin; a Public Affairs Division, led by Matthew Heyman; a Plant Division, under Jorge R. Urrutia; a Facilities Services Division, headed by Walter J. Rabbitt; an Occupational Health and Safety Division, under Lyman E. Pevey; an Acquisition and Assistance Division, led by Richard E. de la Menardiere; a Boulder Executive Office, under Paige L. Gilbert; and a Boulder Technical Services Division, headed by Henry W. Tyler.

A group of 8 laboratories completed the traditional portions of NBS:

- An Electronics and Electrical Engineering Laboratory, directed by Judson C. French, included an Electricity Division, headed by Oskars Petersons, that was responsible for the standards of electricity; a Semiconductor Electronics Division, under Frank F. Oettinger; a Boulder Electromagnetic Fields Divsion, led by Ramon C. Baird; and an Electromagnetic Technology Division, under Robert A. Kamper, who also functioned as Director of the Boulder Laboratories, reporting directly to Lyons.

- A Manufacturing Engineering Laboratory, directed by John A. Simpson, included a Precision Engineering Division, under Dennis A. Swyt; an Automated Production Technology Division, led by Donald S. Blomquist; a Robot Systems Division, under James S. Albus; a Factory Automation Systems Division, led by Howard M. Bloom; and a Fabrication Technology Division, under Adrian W. Moll.

- A Chemical Science and Technology Laboratory, directed by Harry S. Hertz, included a Biotechnology Division, under Lura J. Powell; a Boulder Chemical Engineering Division, under Larry L. Sparks; a Chemical Kinetics and Thermodynamics Division, under Sharon Lias; an Inorganic Analytical Research Division, led by James R. DeVoe; an Organic Analytical Research Division, under Willie E. May; a Process Measurements Division, headed by Hratch G. Semerjian; a Surface and Microanalysis Science Division, headed by Rance A. Velapoldi; and a Thermophysics Division, led by Richard F. Kayser.

Included within the Biotechnology Division of the Chemical Science and Technology Laboratory was a relatively new unit called Advanced Research in Biotechnology. Like other new technology outreach programs, it was a joint venture for academic, government, and industrial scientists. The program sprang from a desire, shortly after the 1978 Bureau reorganization, to create an effective role for NBS in the biological sciences. Director Ernest Ambler, John Hoffman, and Donald R. Johnson were involved in the effort, although the bulk of the organizational work was accomplished by Johnson.

As a result of visits to industrial biotechnology laboratories, Johnson became convinced that an initiative in biotechnology could be coupled with a long-desired NBS goal to create university classrooms near the NBS Gaithersburg campus.

Drawing on experience gained as a Gaithersburg city planner and a member of the Montgomery County High-Technology Council, Johnson collaborated with Rita Colwell of the University of Maryland—who envisioned the new NBS entity as part of a University of Maryland Biotechnology Institute—to convince NBS management, the state of Maryland, the University of Maryland, a philanthropic trust, and Montgomery County to jointly found a Center for Advanced Research in Biotechnology, eventually housed in its own classroom building.[10] Johnson became its first director.

- A Physics Laboratory, directed by Katherine B. Gebbie. It included an Electron and Optical Physics Division, led by Charles W. Clark; an Atomic Physics Division, under Wolfgang L. Wiese; a Molecular Physics Division, headed by Alphonse Weber; a Radiometric Physics Division, led by Klaus D. Mielenz; a Quantum Metrology Division, headed by Richard D. Deslattes; an Ionizing Radiation Division, led by Randall S. Caswell; a Boulder Time and Frequency Division, under Donald B. Sullivan; a Boulder Quantum Physics Division, under David W. Norcross; and a Radiation Source and Instrumentation Division, under P. H. Debenham.
- A Materials Science and Engineering Laboratory, directed by Lyle H. Schwartz, included an Office of Nondestructive Evaluation, headed by H. Thomas Yolken; a Ceramics Division, under Stephen M. Hsu; a Boulder Materials Reliability Division, led by H. I. McHenry; a Polymers Division, headed by Leslie E. Smith; a Metallurgy Division, under E. Neville Pugh; and a Reactor Radiation Division, headed by J. Michael Rowe.
- The Building and Fire Research Laboratories were combined, despite apparent instructions to the contrary in PL 100-418. Richard N. Wright, veteran in the building-technology area, was named Director, and Jack E. Snell, former director of the Center for Fire Research, was made Deputy Director. Included in the new entity were a Structures Division, under Hai S. Lew; a Building Materials Division, led by Geoffrey J. Frohnsdorff; a Building Environment Division, led by James E. Hill; a Fire Science and Engineering Division, under Andrew Fowell; and a Fire Measurement and Research Division, under Richard G. Gann.
- Two computer-based laboratories completed the NIST structure in March 1991. One, a Computer Systems Laboratory, directed by James H. Burrows, included an Information Systems Engineering Division, under David K. Jefferson; a Systems and Software Technology Division, led by Allen L. Hankinson; a Computer Security Division, under Stuart W. Katske; a Systems and Network Architecture Division, headed by Kevin L. Mills; and an Advanced Systems Division, led by Shukri A. Wakid.

[10] Donald R. Johnson, Oral History, September 8, 1998.

A second computer laboratory, called the Computing and Applied Mathematics Laboratory, directed by Francis E. Sullivan, included an Applied and Computational Mathematics Division, led by Paul T. Boggs; a Statistical Engineering Division, under Robert J. Lundegard; a Scientific Computing Environments Division, headed by Sally E. Howe; A Computer Services Division, headed by Martin R. Shaver; a Computer Systems and Communications Division, under Stephen White; and an Information Systems Division, headed by Patsy B. Saunders.

The new structure, with some 18 office and laboratory directors reporting directly to Lyons, would have been thought unwieldy in many organizations. Nevertheless, it remained in effect during the balance of Lyons' tenure as Director. Lyons recalled later that the communications problem was eased considerably by the ubiquity of electronic mail.

Staffing Changes by Lyons

During his tenure as Director, Lyons, as might be expected, made many changes in staffing. Those assigned at the division level or higher, along with the reference in the NBS Administrative Bulletin (NBS Admin. Bull.) series, follow:

- Ellen M. Dowd, Personnel Officer: Nominated, NBS Admin. Bull. 91-5, April 4, 1991; Confirmed, NBS Admin. Bull. 91-10, July 10, 1991.

- Blaine R. Bateman, Chief, Boulder Chemical Engineering Division: NBS Admin. Bull. 91-11, August 9, 1991.

- Albert C. Parr, Chief, Radiometric Physics Division: NBS Admin. Bull. 91-11, August 9, 1991.

- Radiation Source and Instrumentation Division abolished: NBS Admin. Bull. 91-12, September 30, 1991.

- Allen C. Newell, Chief, Boulder Electromagnetic Fields Division: NBS Admin. Bull. 91-15, October 6, 1991.

- Stephen Freiman, Acting Chief, Ceramics Division: Nominated, NBS Admin. Bull. 91-17, October 6, 1991; Confirmed, NBS Admin. Bull. 93-2, November 1, 1992.

- Bruno Fanconi, Acting Chief, Polymers Division: NBS Admin. Bull. 91-17, November 3, 1991.

- Samuel Kramer, Deputy Director, NIST: NBS Admin. Bull. 92-1, December 29, 1991.

- Harry Hertz, Deputy Director, Office of Quality Programs: NBS Admin. Bull. 92-5, April 5, 1992.

- Hratch G. Semerjian, Director, Chemical Science and Technology Laboratory: NBS Admin. Bull. 92-5, April 5, 1992.

- Marvin A. Bond, Acting Director, Office of Information Services: NBS Admin. Bull. 92-12, October 4, 1992.
- Metric Program, reassigned from the Department of Commerce Technology Administration to NIST Technology Services: NBS Admin. Bull. 92-15, November 13, 1992.
- Paul Vassallo, Director, Office of Information Services: NBS Admin. Bull. 93-2, January 10, 1993.
- Gregory J. Rosasco, Chief, Process Measurement Division: NBS Admin. Bull. 93-2, October 4, 1992.
- Richard D. Suenram, Acting Chief, Molecular Physics Division: NBS Admin. Bull. 93-2, October 4, 1992.
- Joan R. Rosenblatt, Director, Computing and Applied Mathematics Laboratory: Nominated, NBS Admin. Bull. 93-3, February 14, 1993; Confirmed, 93-10, May 2, 1993.
- Chemical Engineering Division abolished: NBS Admin. Bull. 93-9, November 27, 1992.

Strategic Planning

During 1991, John Lyons and his senior managers prepared a 10-year strategic plan for NIST.[11] The plan was based upon three assumptions: that industrial competitiveness would continue to be a top priority for the Department of Commerce; that Commerce would continue as the focus of programs in that area; and that Commerce would support the mission with lively programs to improve industrial technology.

The NIST vision included the following items:

- Doubling of the NIST laboratory budgets.
- Even faster growth for the Advanced Technology Program.
- Modernization of the NIST laboratory facilities.
- Expansion of the Manufacturing Technology Centers program to span state, local Federal, and private-sector technology efforts.
- Tighter coupling between the internal NIST programs in science and engineering and the outreach programs.
- Expansion of the Quality Program to include non-profit organizations in health care and education.
- Addition to U.S. embassies abroad of "Technology Attachés," whose duties would include gathering information on foreign technical projects, as well as the promotion of U.S. technology-based products.

[11] "NIST in the 1990s: The Strategic Outlook," February 1991.

A second management tool prepared by NIST in 1991 was a Research Relationship Handbook, intended to guide NIST staff and potential industrial partners in selecting and establishing collaborative projects. Included in the handbook were:

- Types of organizations to be involved—all U.S. entities.
- Types of activities covered—Cooperative Research and Development Agreements, Proprietary Measurement Agreements, licenses, non-disclosure agreements, guest researchers, and gifts and loans of equipment.
- A "decision tree" for use in selecting appropriate interaction mechanisms.

Personnel Policy

The NBS Authorization Act for Fiscal 1987 designated NBS as the site of a Personnel Management Demonstration Project. Based on a similar project in one of the U.S. Navy research laboratories, the plan was intended to accomplish several goals, partly for NBS and partly for broader use within the Federal government:

- Simplified position classification based on knowledge, skill, and duties.
- Separate career paths—Scientific and Engineering Professional, Scientific and Engineering Technician, Administrative, and Support.
- "Pay banding" into five broad salary ranges within each career path.
- "Pay for Performance," which tied salaries to performance appraisals.
- Direct hiring authority for new employees.

The new personnel policies developed within the Demonstration Project improved the ability of NBS/NIST to attract and retain well-qualified staff in all personnel areas. The length of the hiring process was reduced considerably—by a month or more—improving the NIST competitive edge in the competition for highly qualified candidates.

The flexibility gained by enabling line managers to recommend incentive bonuses and rapid salary increases for deserving employees offered a powerful motivational tool. At the same time, the program reduced the manager's paperwork burden.

The 1990 Report of the Visiting Committee on Advanced Technology

Public Law 100-418 required the Visiting Committee on Advanced Technology (VCAT)—larger and with more responsibility than its predecessor—to meet quarterly rather than annually. This more intense schedule produced a more tightly focused agenda and considerable detail in the VCAT reports.

New VCAT Members

By the time that the VCAT had prepared its 1990 annual report, a new chairman—Arden L. Bement, Vice President for Science and Technology, TRW Corporation—had succeeded William D. Manly. Other new members of the committee were Edward C. Heffron of the Michigan Department of Agriculture; Richard S. Nicholson, Executive

Officer of the American Association for the Advancement of Science; Nam P. Suh, professor of Mechanical Engineering at MIT; and Albert R. C. Westwood, Vice President for Research and Technology at Martin Marietta Corporation. These men succeeded Nolen M. Ellison, president of Cuyahoga Community College; John P. McTague, Vice President for Research at Ford Motors Corporation; and William J. Spencer, Vice President for Research at Xerox Corporation.

NIST Organization

The VCAT expressed admiration for the way in which Kammer and Lyons had revamped the NBS organization to create a NIST that could fulfill the goals mandated by PL 100-418. The committee urged the Department of Commerce and the Congress to note the early success of NIST in raising the level of technology in the U.S. industrial sector, and to solidify the gains by helping NIST to evolve into something like the industrial equivalent of the National Institutes of Health in medicine and the Defense Advanced Research Projects Agency in the military.

Manufacturing Technology Centers

The VCAT visited the three Manufacturing Technology Centers during June 1990 as part of a detailed inquiry into the suitability of the program to assist small- and medium-sized companies in the assimilation of new technology. The committee was pleased with early results; center clients reported technical gains worth a cumulative $75 million during the first 18 months. The committee recommended that the program be expanded to include as many as 12 centers at a time.

Advanced Technology Program

The VCAT also examined the joint-venture technology development and commercialization program initiated as part of the Advanced Technology Program. The program made use of two significant definitions:

- Precompetitive research: research and development up to the point where commercial potential can be evaluated.
- Generic technology: concepts, components, or processes with the potential for generating a broad range of products or manufacturing methods.

The committee recommended several steps for program implementation:

- Include the broadest possible range of American industry in the selection of candidate technologies.
- Refine the technology selection process to include a "discovery" phase to weed out inappropriate ideas generated by the Request for Proposals (some 249 proposals had already been received) and a second, more comprehensive, proposal phase focused on those technologies.

- Refine the program management to develop better interaction between the NIST program and industry, focusing on three to five areas at first, but preparing to expand the program as it succeeded.
- Carefully protect proprietary aspects of companies involved, paying particular attention to intellectual property rights and antitrust liability.

Baldrige Quality Award

The VCAT noted that the Baldrige Quality Award program was drowning in its own success. More than 100,000 copies of the applications guidelines were distributed during 1990 alone. Many firms used the guidelines as self-evaluation tools without regard to potential submission of applications for the prize. Over the 3-year life of the program, it had become extremely successful and, said the committee, needed Federal funds to augment the private monies that thus far had provided its support. Such an increase would permit the addition of staff to process the growing numbers of submissions and requests for information.

NIST Budget

The VCAT noted a distinct improvement in the NIST budget with the Fiscal 1991 appropriation. Funding for laboratory initiatives was paralleled by growth in the allocations for the ATP and the MTC programs.

Cautionary alarms were sounded, however, regarding the state of the NIST physical plant, by then approaching 30 years of age. Critical areas noted were laboratory-space environmental controls (temperature, humidity, vibration, and air filtering), safety systems, and utilities.

NIST RECEIVES AN EXAMINATION

During Fiscal 1992, the National Research Council Board of Assessment took a long look at the progress made by NIST following passage of the Omnibus Trade and Competitiveness Act of 1988. The Board members liked what they saw, although they made numerous suggestions.

The objectives Congressionally mandated for NIST in 1988 became three in number; to enhance the technical competitiveness of U.S. industry, to maintain the traditional measurement programs, and to solve technical problems of national importance. The Board found that NIST had made excellent progress in meeting its new challenges: "The Board considers conditions and trends at NIST to be better now than at any time in recent history."

In assessing the situation at NIST, the Board used more than 150 technical assessors who visited the 10 NIST operating units. These operating units and their financial support levels from Congress (Approp) and from other Government agenices (OA) are shown in the following table:

NIST Unit	FY91 $M Approp	OA	Total
Electronics and Electrical Engineering Laboratory	20.0	19.3	39.3
Manufacturing Engineering Laboratory	10.0	17.3	27.3
Chemical Science and Technology Laboratory	24.6	19.2	43.8
Physics Laboratory	23.6	13.0	36.6
Materials Science and Engineering Laboratory	32.4	17.2	49.6
Building and Fire Research Laboratory	10.7	10.2	20.9
Computer Systems Laboratory	12.3	14.4	26.7
Computing and Applied Mathematics Laboratory	14.6	5.7	20.3
Technology Services	19.6	13.5	33.1
Director of Administration	----	----	----
Total Support	167.8	129.8	297.6

At the heart of NIST's response to its new challenges was a 10-year master plan, "NIST in the 1990s, the Strategic Outlook," issued by Director John Lyons on February 6, 1991 (see previous section). The plan assumed that the level of U.S. industrial competitiveness would continue to dominate Commerce Department and Congressional thinking over the coming decade, and that Commerce would develop its own program to complement that of NIST. Another assumption was that Congressional funding would reflect its commitment to NIST's goal.

Based on these assumptions, the 10-year plan envisioned a doubling of NIST laboratory budgets and modernization of NIST laboratory facilities; an Advanced Technology Program that would accelerate in order to address more industrial needs; increases in the program budget for the Manufacturing Technology Centers; increased synergism between the intramural NIST technical program—which would help create new technology—and the extramural program—which would help commercialize the new technology and assess new industrial needs; broader scope for the NIST Quality Outreach Program to include non-profit organizations as well as industrial firms; and moves by standards experts to join embassy teams throughout the industrially oriented world to collect and disseminate technical information.

The Board urged that NIST increase the effort to bring industry into fuller participation in strategic planning for the 1990s, and develop measurement techniques for evaluating the success of its program.

The Board noted that funding for the Standard Reference Data and Standard Reference Materials programs had effectively decreased over the previous decade, and that that trend had been deepened by the commitment of NIST resources to the new programs. The Board urged NIST management to reverse that trend, because of the proven value of the SRD and SRM programs to industry.

Fundamental, long-term research also had suffered during recent years, according to the Board. The funding target declared by NIST management for basic work—15 % of each year's appropriation—was a modest one by industry standards. As much as 20 % would have been more in line with industrial practice.

Yet another area that was under-funded, in the view of the Board, was that of building new NIST capabilities through the Competence Building Program. The total of $27 million spent since 1979 had been too small by at least a factor of two, in the Board's opinion.

Furthermore, the NIST management ran the program as a contest, rather than as an integral part of strategic planning with long-lasting support to fully establish new areas of competence.

The Board report quoted a recent report by the Office of Technology Assessment:[12]

> There is a clear need in the United States for greater attention to standards. In an information-based global economy, where standards are not only employed strategically as marketing tools but also serve to interconnect economic activities, inadequate support for the standard-setting process will have detrimental effects.

Adequacy of NIST's equipment and facilities was another concern expressed in the Board report. In many cases, found the Board's investigators, NIST staff was forced by circumstances to improvise or borrow needed equipment.

The Board suggested that the principles of Total Quality Management be extended at NIST to all levels of the organization.

The report closed with suggestions for new approaches to the challenges facing NIST. Three of these were intended to be applied throughout NIST:

- Utilize specialized management training to facilitate cooperation with industry. If such training is not available, create it.
- Create a "technology transfer organization"—preferably in concert with industry—to facilitate commercialization of new technology.
- Make increasing use of interdisciplinary teams built from various NIST units, perhaps in collaboration with industrial or academic colleagues, to foster technology transfer to industry.

In addition to the suggestions for NIST generally, members of the various panels of the Board made many detailed suggestions that applied to the individual units of NIST listed in the previous table.

The report was powerful in its support of NIST and extremely thorough in the depth of its coverage of the various NIST laboratories.

In 1992 testimony before the Congressional Subcommittee on Technology and Competitiveness, Lyons reinforced the concerns of the Board of Assessment, citing an internal review of the state of the NIST laboratories. He noted that many of the NIST laboratory buildings were no longer equal to modern scientific demands. Such problems as ubiquitous dust—let alone a lack of critical services—rendered some of the laboratories unfit for specialized investigations. Lyons found this to be a double problem: not only did laboratory conditions impair scientific progress, but they made it increasingly difficult to retain some of NIST's most accomplished scientists, who routinely received offers of higher pay and better facilities elsewhere.

[12] "Global Standards: Building Blocks for the Future," *Office of Technology Assessment Report*, 1992, p. 9.

A Politicized Agency?

The Trade Act of 1988 certainly raised the profile of NBS/NIST. The success of the Technology Extension Program, with its Manufacturing Technology Centers; the growth of the Advanced Technology Program; the popularity of the Baldrige Quality Award; and the emphasis on industrial productivity generated in the balance of NIST's laboratories brought the agency more and more to the attention of America's technical establishment. Business and political leaders saw NIST as a leading agency in the technology effort of the Department of Commerce. Further, NIST became a helpful source of funds for research into advanced manufacturing by American companies.

However, with increased attention and increased budgets came unavoidable consequences. One of these appeared when the Clinton administration replaced the Bush team. Instead of treating NIST as NBS and other apolitical agencies had been treated, the new administration considered NIST as one of many departments and agencies whose leadership should be chosen to reflect "correct" thinking on economic and political issues. Despite the obvious successes of NIST during the Bush administration, a Department of Commerce order early in 1993 moved John Lyons to the position of Acting Undersecretary for Technology. Raymond Kammer once again became Acting Director of NIST.[13]

Arati Prabhakar, director of the Microelectronics Technology Office of the Defense Advanced Research Projects Agency, a Defense Department unit, appeared to the administration to be an excellent choice for Director of NIST on account of her experience with an agency that supported many external grants. She was duly nominated for the post of Director, NIST, and confirmed by the U.S. Senate on May 28, 1993.[14]

Under the Clinton administration, the framework created by the Omnibus Trade and Competitiveness Act of 1988 remained essentially intact. In fact, the administration supported substantial funding increases for the Advanced Technology Program and the Manufacturing Extension Center activities.

Technical Work of NIST, 1990-1993

Technology Outreach Programs

Advanced Technology

In mandating the Advanced Technology Program (ATP) for NIST as part of the 1988 Trade Act, Congress sought to make use of the technical sophistication of NIST scientists and engineers to identify promising new industrial ideas. Selected projects would be given Federal support during the crucial period of investigation that necessarily preceded the development of a product, with NIST helping to reduce the high risk inherent in the projects. After considerable discussion between NIST management and the Bush administration, funding became available for the development of "generic, precompetitive" technologies by individual firms or by industry-dominated joint ventures.

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[13] John Lyons, Oral History, June 9, 1993.

[14] NIST Admin. Bull. 93-12, June 4, 1993.

The first person named to head the ATP was Donald R. Johnson, who had participated in planning the program at the request of Ernest Ambler. When the new NIST structure was formally approved on January 4, 1991, however, it included a major unit called Technology Services. Johnson immediately was re-assigned to the position of director, Technology Services, with George A. Uriano succeeding him as director of ATP. Brian C. Belanger was appointed deputy director. The ATP force was never large—numbering but 10 people in 1991—although it administered millions of dollars in contract funds.

Public Law 100-418 limited the amounts of the grants to individual companies to $2 million over a 3-year period. For joint ventures, the grants could be larger, depending on the projects, and they could be continued up to 5 years. The program was intended to be a cost-sharing one, so that all grantees would be seriously committed to their projects.

As NIST gained experience with the ATP concept, Uriano and Belanger made extensive use of industrial representation to identify promising technical areas. They also followed examples from other more-experienced Federal-grant organizations such as the National Institutes of Health and the Defense Advanced Research Projects Agency. Quickly, the NIST ATP reached a workable approach to its responsibility:

- Competitive selection of grantees. Each proposal was examined to see that it conformed to the basic requirements of the program, then given comprehensive reviews by experts in the technical area of the proposal. Further reviews of promising proposals evaluated their potential economic impact and the level of corporate commitment implicit in the presentation. To minimize the conflict of interest that would arise from reviews by industrial personnel, only Governmental and academic scientists and engineers served as technical reviewers; business-related evaluations were performed by industrial consultants who were required to avoid conflicts of interest and to preserve proprietary confidentiality. Proposals were ranked according to published criteria, and awards were based on the ranking.

- Direct support to for-profit firms. Grants were awarded to start-up companies as well as small, medium, and large firms, and to joint ventures. The joint ventures could include universities, governmental organizations, or non-profit groups as sub-contractors or partners.

- Economic goals. The ATP, designed to "rapidly commercialize new technologies," continually maintained as its primary goal the economic success to be derived from its awards. The program supported both new products and lower-cost production methods. By supporting commercial firms, the ATP could rely on strong grantee commitment to financial success.

- Monitoring of performance. ATP managers quickly developed a plan for continuous monitoring of the performance of its grantees. Measurable goals were defined for the critical aspects of each successful proposal.

Independent studies of the ATP undertaken in 1991 showed that the program was quickly bearing fruit. Publication of program criteria provided businesses—particularly smaller firms—with yardsticks by which they could measure their own efforts to bring new technologies to market. The studies detected increased industrial research and development activity, higher productivity, and quicker time-to-market for new products and processes.

Viewpoints of industry on the ATP program were expressed by many individuals and groups. Senior industrial managers provided direct guidance on research priorities. Professional societies and trade associations yielded yet other suggestions. On occasion, NIST sponsored workshops and conferences specifically intended to generate ATP program input from a variety of sources. The file of ATP proposals also provided useful information for program direction.

Brief sketches of successful proposals up to 1993 illustrate the breadth of the ATP:

- Creation of generic computer software for use with motion pictures—to digitally restore, re-format, or enhance sequences of infrared, x-ray, or motion-picture images.
- Design for multiple-axis machine tools of high precision, based on an octahedral frame.
- A low-cost, automated DNA sequencer, incorporating on a single microchip synthetic DNA probes and computer sensor technology.
- High-temperature-superconductor-based thick-film processing technology for radio-frequency communications components.
- Erasable optical disk drive, using an electron trapping optical memory, for high-speed digital video recording.
- Gas-phase cleaning agents for removing surface damage, trace metals, and particles from semiconductor wafers.
- Improved production technology for lasers and light-emitting diodes.
- New technology for designing and analyzing thermoplastic parts in terms of microstructure, geometry, and performance.
- Production technology for ductile, metallic glass ribbon for use in high-power, low-loss electric transformers and motors.

Early in 1995, Lura J. Powell succeeded George Uriano—retiring after more than two decades of service to NBS/NIST—as director of the ATP. Brian Belanger remained as her deputy. As the program expanded, it became necessary to divide responsibility for its various aspects. To this end, Powell created five offices during 1996. These were:

- Economic Assessment, under Rosalie T. Ruegg.
- Information Technology and Applications, under Bettijoyce B. Lide.

- Chemical and Biomedical Technology, under Stanley Abramowitz.
- Materials and Manufacturing Technology, under John P. Gudas.
- Electronics and Photonics, under Brian Belanger.

Still later, an Office of Programs and Information Management was formed under the direction of Alvin H. Sher.

William F. Long of Business Performance Research Associates wrote a critique of the ATP in 1999.[15] His report focused on the first 8 years of the program. During that period, 1990-1998, the ATP received more than 3,500 proposals; 431 of these were selected for funding. Long estimated the total cost of the funded projects to be $2.8 billion. The industrial proposers provided slightly more than half of that sum, with ATP supplying the rest.

As of March 1997, 38 of the projects were completed—final project reports had been submitted and financial and other required data had been supplied to ATP—and another 12 had been terminated prior to completion. Long and his colleagues analyzed the 38 completed projects to assess the significance of the ATP for American industry.

Individual firms—27 with fewer than 500 employees—accounted for 34 of the successful projects. None received more than the $2 million grant from ATP allowed by PL 100-418. Most contributed resources worth as much as the Federal funding; eight firms spent about twice as much of their own funds as the amount of the grant. Of the four joint-venture grants, three received ATP funding of $5 million or less, while one received between $5 million and $10 million.

Almost half of the completed projects involved electronics; the rest were distributed among the areas of computers and communications, biotechnology, energy and environment, manufacturing, materials, and chemicals.

Industry gains from the completed projects could not be assessed accurately because, for most of the projects, the "bottom line" was still under evaluation by the participants. However, estimated returns on project efforts were offered by a few participants:

- Auto Body Consortium, consisting of nearly a dozen industrial and academic entities involved in automobile production, estimated that their "2 mm" project—devoted to reducing assembly-line errors to 2 mm or less—might return $3 billion from quality improvements in American cars. By 1999, the new technology was in use in about half of the U.S. Chrysler and General Motors assembly plants.
- Aastrom Biosciences, involved in a human-stem-cell-production project, projected its return at nearly $1 billion.
- Tissue Engineering, a biotechnology start-up company working toward regeneration of body tissue to avoid the need for artificial replacements, projected return on its project investment at $1 billion or more.

[15] William F. Long, "Advanced Technology Program: Performance of completed projects. Status report No.1," *NIST Special Publication 950-1*, March 1999, 134 pp.

Nearly two dozen of the completed project statements reported that the new technology had already led to new or improved commercial products or processes—some of them anticipated, some serendipitous. Some of the projects received recognition in the form of awards:

- Superconducting wire fabrication and winding techniques, a project of the American Superconductor Corporation, received a 1996 R&D 100 award from *Research and Development* magazine. It also was named a Technology of the Year (1996) by *Industry Week* magazine. Once the ATP project began, the company received support—previously unavailable—from the U.S. Department of Energy.

- Software that recognized handwriting for computer input, developed by Communication Intelligence Corporation, received the "Ease-of-Use Seal" of the Arthritis Foundation in 1997.

- Thallium-barium films for superconducting electronic devices, a project of E.I. du Pont de Nemours & Company, was recognized as one of the "Top Products of 1993" by *Microwaves and RF* magazine.

- Animated three-dimensional representations of the human body, developed by Engineering Animation, Incorporated, received the Smithsonian Award in 1994 for the use of information technology in the field of medicine, given by *Computerworld* magazine. The procedures also received two 1995 awards for animation from the Association of Medical Illustrators and the "Annie" award from the motion picture film industry, as well as a 1996 "25 Technologies of the Year" award from *Industry Week* magazine.

- Robots for transporting medicines in hospitals, a project of HelpMate Robotics, Inc., received the Japan prize in 1997 from the Science and Technology Foundation of Japan.

- Cellular telephone site filters and superconducting ceramics, developed by Illinois Superconductor, Inc., received the *Microwave and RF* magazine award as one of the Top Products of 1996, and the 1997 Corporate Technical Achievement Award of the American Ceramic Society.

The ATP funding received lavish praise from participating companies. Two-thirds of the successful participants testified that their projects would not have been undertaken without the stimulus provided by the program. The others expressed the belief that, without ATP funding, their projects would have been delayed by 18 months to 5 years. Clearly the Advanced Technology Program placed the NIST in the right place at the right time with the right leadership to the benefit of U.S. industry.

Quality Programs

The General Accounting Office did not give praise lightly. Both NIST director John Lyons and Curt W. Reimann, director of Quality programs, were edified, therefore, that a GAO report, written less than three years after the Malcolm Baldrige National Quality Award was established late in 1988, described its selection criteria in glowing terms:[16]

> [It is] the most widely accepted formal definition of what constitutes a total quality management company. In nearly all cases, companies that used total quality management practices achieved better employee relations, higher productivity, greater customer satisfaction, increased market share, and improved profitability.

The Baldrige Award, described in *The Malcolm Baldrige National Quality Award,* Chapt. 4, was an instant success. Its selection criteria, developed in consultation with industry, provided many a company with a useful guide to evaluating its approach to business. The awards themselves lent prestige to the winning firms. Indeed, a letter from Solectron Corporation, a 1991 awardee, to the Secretary of Commerce indicated more tangible benefits as well:

> Since we applied for the Malcolm Baldrige award in 1989, Solectron's sales have increased 316 % and profit has increased 338 % in 3 years.
> We attribute our financial performance a great deal to the improvement we made through the rigorous examination and feedback from the Baldrige application process.

The award guidelines touched upon seven areas of quality in industrial performance:

- Leadership in setting goals for quality and paths to reach them.
- Information and analysis that is timely, reliable, and accessible.
- Strategic quality planning, integrated into the overall company business plan.
- Human resource development and management to maximize employee potential for quality work.
- Management of processes to achieve quality results.
- Evaluation of the quality and trend of company operations.
- Customer focus and satisfaction.

Financial support of the Baldrige award initially was provided by industry, although the NIST staff members who administered the program were supported internally. Eventually, NIST management was successful in obtaining Congressional funding for the program.

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[16] "Malcolm Baldrige National Quality Award," pp. 7, 15 in "Guide to NIST," *NIST Special Publication 858,* October 1993.

Quality experts from both the public and private sectors joined in independent reviews of the many applications received each year; those selected as outstanding received on-site visits to flesh out details of their quality programs. All applicants received written summaries of their quality operations.

Curt Reimann remained in charge of the Baldrige award program until 1996, when he retired. He was succeeded by Harry S. Hertz.

Technology Services

Among the most visible of the NIST outreach programs were those adminstered through Technology Services:

- *Manufacturing Technology Centers,* which by 1993 numbered seven, were located in California, Ohio, Kansas, Michigan, New York, South Carolina, and Minnesota. The MTC were set up mainly for the benefit of small- to mid-sized companies.

  Each center tailored its services to the needs of its manufacturing client base, usually offering assistance in the form of individual project engineering, training courses, demonstrations of equipment and procedures, and advice on the selection and use of tools and software. Visits to client plants and on-site advice on installations proved beneficial, as did consultation on management, finances, marketing, and employee training.

  Equipment available for demonstration generally included automated lathes and milling machines, industrial robots, and state-of-the-art measurement instruments.

  The success of the program was measured in terms of progress made by clients of the MTC. The average gains by such firms included an increase in the numbers of employees by 15 %, a 7 % increase in productivity, and an astonishing 34 % increase in sales. The total Federal investment in the MTC—about $18 million from January 1989 to June 1991—resulted in total savings to the client companies of nearly $140 million.

  Richard D. Suenram described several case histories illustrating the variety of assistance provided to client firms by the MTC.[17] The firms discussed ranged in size from 27 employees to 174. Their products and the technologies involved included acrylic residential countertops (computer-controlled routing of one-of-a-kind designs), metallizing of plastic bottle caps (introduction of ultraviolet-light curing, eliminating dust), prosthetic hip and knee joints (computer aided design and manufacturing), high-volume, low-pressure paint spray equipment (plant layout, multi-purpose computing), automated machine tools (multi-purpose computing, automated measurements), surgical-instrument sterilizing equipment (computer-aided design and manufacture), roller bearings (process development and control, measurement), industrial cleaning equipment (computer modeling, videotaping), nuclear magnetic resonance spectrometers (manufacturing process design).

[17] Richard Suenram, "The Manufacturing Technology Centers program: A sampling of individual case histories," *NIST Special Publication 830,* February 1992, 21 pp.

• *State Technology Extension Programs (STEP),* initially known as the Boehlert-Rockefeller Technology Program, provided assistance in developing the infrastructure needed by the various states to assemble their own programs to help smaller manufacturing businesses. The STEP emphasized use of the Manufacturing Technology Center capabilities, local university centers, and community college programs in manufacturing technology.

Among the methods used by the state programs were industrial extension agents to provide advice on the use of new technologies and pilot projects in important sectors of the state's industry. Grants, to be matched dollar for dollar by sponsoring organizations, could be allocated to non-profit institutions as well as state agencies.

During 1993, both the Manufacturing Technology Centers and the State Technology Extension Program became part of a *Manufacturing Extension Partnership Program* (MEPP) mandated by President Clinton. Clinton, recognizing a concept with the potential of benefitting the economy, hoped to see "over 100 manufacturing extension centers nationwide by 1997 to assist manufacturers to modernize their production capability." Philip N. Nanzetta was named head of the MEPP.

• *Office of Standards Services* provided assistance on national and international standards and certification activities. Through the U.S. Interagency Committee on Standards Policy, for which NIST served as the secretariat, the OSS published guidelines for Federal participation in standards creation and laboratory accreditation.

By this time the issue of international industrial standards was critical for U.S. firms participating in international trade. Thousands of U.S. standards affected domestic sales as well. Guiding American businesses through the maze of standards aided them greatly in their efforts to efficiently manufacture and sell their products. In 1992, Stanley I. Warshaw directed the office. Along with his deputy, Walter G. Leight, Warshaw coordinated the work of a *Standards Code and Information* program headed by John L. Donaldson, a *Standards Management* program led by Samuel E. Chappell, a *Weights and Measures* program headed by Carroll S. Brickenkamp, and a *Laboratory Accreditation* program under Albert D. Tholen.

• *Standards Management* administered U.S. participation in the International Organization of Legal Metrology (OIML), as well as the *Voluntary Product Standards* program of the Department of Commerce. Effective representation in OIML of U.S. positions on trade standards was an important part of ensuring fair treatment for American products in foreign markets—OIML involved more than 80 nations in its deliberations.

In the tiny unit, Samuel E. Chappell directed the work of Otto Warnlof, Barbara Meigs, and Rachel R. Phelps, who solicited technical advice from U.S. trade associations, instrument manufacturers, universities, and other government agencies to develop a U.S. viewpoint on OIML draft standards documents. They also assisted NIST scientists who participated in OIML meetings as technical experts.

• *Weights and Measures,* an ancient arm of NBS/NIST, provided an accreditation program for state weights and measures laboratories in mass, length, and volume. In addition, the NIST office, headed in 1992 by Carroll S. Brickenkamp, offered training programs and advice on testing methods.

In a 1993 NIST publication, Georgia L. Harris described the state standards program of the state weights and measures system and identified the capabilities of the member laboratories.[18] Under terms of its 1965 congressional mandate, NIST provided training to state metrologists in NIST testing procedures and conducted a voluntary accreditation program for state weights and measures laboratories.

To qualify for accreditation, state laboratories were required to:

- Maintain resources—laboratories, equipment, and personnel—adequate to perform standards measurements.
- Employ a trained metrologist who could demonstrate use of program test procedures.
- Establish measurement controls, based upon NIST standards, for each area.

The areas of measurement included in the accreditation program were divided into two classifications—tolerance testing and calibration. Tolerance testing, determining whether a given actual standard was sufficiently close to its nominal value, was accomplished in mass and volume. Calibration, the assignment of a value and an uncertainty to a working standard, applied to mass, volume, length, frequency, and temperature.

NBS Handbook 143, *State Weights and Measures Laboratories—Program Handbook,* provided guidance for the state metrologists, including a self-appraisal checklist. Six regional round robin measurement assurance programs conducted by NIST metrologists served to evaluate the accuracy of the state measurements.

Besides the 50 state laboratories, accreditations had been earned by the city of Los Angeles, the Virgin Islands, and the U.S. Department of Agriculture.

The NIST Weights and Measures office also provided leadership for the National Conference of Standards Laboratories (NCSL), an organization devoted to developing and maintaining measurement standards. More than 3000 members of NCSL represented the standards interests of industrial, academic, and governmental organizations. Annual NCSL meetings served as a forum for dissemination of the latest information on standards and for discussion of outstanding standards problems.

• *Laboratory Accreditation,* headed by Albert D. Tholen, monitored the competence and technical qualifications of testing and calibration laboratories operated by either public or private organizations. The National Voluntary Laboratory Accreditation Program offered its services in several areas of testing: product testing, computer networks, construction materials, electromagnetic

[18] Georgia L. Harris, "State weights and measures laboratories: state standards program description and directory," *NIST Special Publication 791,* 1993 Edition, June 1993, 83 pp.

compatibility, energy-efficient lighting, fasteners, metals, telecommunications, and radiation dosimetry. In calibration, applicable areas included electrical quantities, dimensional measurements, radiation, mechanics, thermodynamics, time, and frequency.

- *Standard Reference Data* By 1993, the 30-year-old Standard Reference Data program administered a national network of scientists devoted to the critical examination of data and offered to the public a large group of databases containing the fruits of their labors. In addition, the program continued publication of the *Journal of Physical and Chemical Reference Data.* Malcolm W. Chase directed the program throughout the tenure of John Lyons.

Initially operating under a 1963 request from the Federal Council for Science and Technology to provide reliable data in the physical sciences through a process of critical evaluation, the program received legal status in Public Law 90-396, the *Standard Reference Data Act of 1968* (see Appendix A).

Evaluation programs, conducted in data centers and cooperative projects located at NIST, in universities, and in industrial research centers, assembled sets of reliable data for use in several fields:

- Analytical chemistry.
- Atomic physics.
- Biotechnology.
- Chemical kinetics.
- Materials properties.
- Molecular structure and spectrsocopy.
- Thermodynamics and thermochemistry.
- Thermophysical properties of fluids.

The 1993 SRD catalog listed more than 40 databases available in electronic form—on computer disks, CD-ROMs, magnetic tapes, and in "online" form.[19]

The *Journal of Physical and Chemical Reference Data,* since 1972 published jointly with the American Chemical Society and the American Physical Society, collected critical reviews of data in dozens of scientific areas. Journal articles were prepared by NBS/NIST authors and by experts from academia and industry. In 1993, Jean W. Gallagher became the editor of the journal, succeeding David R. Lide who had edited the magazine from its inception until well after his retirement from NBS in 1988.

- *Standard Reference Materials* In 1993, NIST offered more than 1200 different Standard Reference Materials. Ranging from chemicals certified for their properties to linewidth standards used in the production of integrated circuits, SRMs provided American science and industry with the capability to achieve and verify accuracy in their measurements. From 1991, measurements

[19] "NIST Standard Reference Data Products Catalog 1993," Malcolm W. Chase and Joan C. Sauerwein, editors, *NIST Special Publication 782*, 1993 Edition, January 1993, 79 pp.

were expressed in SI units;[20] for convenience, customary units could also be listed on SRM certificates. Uncertainty statements were required as well. Stanley D. Rasberry directed the program from 1983 until mid-1991, when he was appointed director of Measurement Services. William P. Reed was named as his successor to head OSRM. Thomas E. Gills became director in 1993.

The catalog of Standard Reference Materials offered its units in a variety of categories.[21] One of the oldest lines contained standards based upon chemical composition. These included ferrous and non-ferrous metals, high-purity materials, microanalytic aids, organic and inorganic materials, health-related items, food references, geologic standards, ceramics, and cement. SRMs defined for physical properties covered such fields as thermodynamics, optics, ionic activity, radioactivity, electricity, length measurements, and polymers. Reference materials for engineering touched upon fire research, surface finish, non-destructive evaluation, automatic data processing, and particle sizing.

John K. Taylor, dean of the NBS/NIST staff in 1986 when he retired after 57 years as an analytical chemist, was up-dating a *Handbook for Users of Standard Reference Materials* at the time of his death on March 26, 1992.[22] Nancy M. Trahey brought the handbook to publication. The text offered a bibliography of nearly 200 monographs describing individual SRMs, in addition to discussions of a whole range of other topics related to their use:

- Precision and accuracy.
- Quality assurance.
- SRM concept, production procedures, and certification.
- Methods of use of SRMs in various applications.
- Guidelines for reporting of analytical data.

Electronics and Electrical Engineering Laboratory

Personnel of the Electronics and Electrical Engineering Laboratory (EEEL) provided primary electrical standards and a raft of related services, including support for the Nation's electronic instrumentation, electronic products, electric utility, and semiconductor industries. Their specialties were to be found also in radio-frequency, microwave, and millimeter wave radiation, in superconductivity, magnetism, and optoelectronics.

The staff numbered over 280 permanent employees and nearly 80 guest scientists participating in various programs. The laboratory calibration program provided nearly 40 % of all NIST calibrations.

[20] "The International System of Units (SI)," *NIST Special Publication 330,* Barry N. Taylor, editor, August 1991, 56 pp.

[21] The "NBS/NIST Standard Reference Catalog" was re-issued periodically as *NBS/NIST Special Publication 260* in order to provide an up-to-date listing of available standard samples.

[22] John K. Taylor, "Handbook for Users of Standard Reference Materials," *NIST Special Publication 260-100,* edited by Nancy M. Trahey, February 1993, 102 pp.

Laboratory management was keenly conscious of the importance of close cooperation with industry, academics, and other Federal agencies (see The More Things Change, The More They Remain The Same: Industrial Productivity in Semiconductors—NIST Prefigured), numbering among its clients some of the tiniest firms as well as the largest. EEEL Director Judson French and his senior management staff had learned from experience how to maximize the effectiveness of the EEEL programs in metrology and associated technology, concentrating their efforts where NIST capabilities intersected with industry needs.

Electricity, Oskars Petersons, chief

Quantum-Based Voltage and Resistance Standards

A document entitled *Guidelines for Implementing the New Representations of the Volt and Ohm, Effective January 1, 1990* was published by Norman B. Belecki, Ronald F. Dzuiba, Bruce F. Field, and Barry N. Taylor in 1989.[23] Issuance of the guidelines was the culmination of brilliant technical work that extended over 20 years. Laboratories contributing to final values for the new standards encompassed the earth, bringing a revolutionary change to two of the oldest standards of physical measurement.

In their note, the authors explained to the reader the meaning of the term "practical representation of the volt," which would replace terms such as "laboratory unit of voltage." Side-stepping the stability problems inherent in the electrochemical cell, the international standards community decided to express the standard of voltage through the use of the superconducting Josephson effect. An analogous substitution was made for the resistance standard, replacing the bank of wire resistors used by most nations as the practical embodiment of the ohm with a representation based upon the quantum Hall effect.

From January 1, 1990, the U.S. representation of the volt based on the Josephson effect, "V(NIST-90)," would employ an assigned value of 483 597.9 GHz/V for the Josephson constant $2\,e/h$. Similarly, the U.S. representation of the ohm based on the quantum Hall effect, Ω(NIST-90), would, from January 1, 1990, employ an assigned value of 25 812.807 Ω for the von Klitzing constant h/e^2. These statements embodied big changes in the technology of electrical standards. We should say "Thank you and goodbye" to the old standards; they had served well.

Electrochemical Cell Calibrations

For a century and a half, electrochemical cells were used as standards of voltage; they had provided NBS with its voltage references from its founding. The history of standard cells at the Bureau was described by Hamer in 1965.[24] The most stable type

[23] Norman B. Belecki, Ronald F. Dzuiba, Bruce F. Field, and Barry N. Taylor, "Guidelines for Implementing the New Representations of the Volt and Ohm, Effective January 1, 1990," *NIST Technical Note 1263, June 1989*, 60 pp.

[24] Walter J. Hamer, "Standard cells, their construction, maintenance, and characteristics," *NBS Monograph 84*, January 1965, 38 pp.

During his tenure at NBS/NIST from 1970 to 2000, Norman B. Belecki led the Electrical Reference Standards group for 25 years. He supervised the change in the electrical standards calibration program from manual to automated measurements and the adoption of primary standards based on quantum phenomena.

of cell, the Weston cadmium cell, dated from 1891.[25] Standard cells were not intended as sources of electric power; therefore, their design differed substantially from such devices as automobile storage batteries or flashlight cells. Enclosed in an H-shaped glass container, each column contained an electrode; the cross-tube contained a saturated cadmium sulfate electrolyte. When carefully prepared and aged and maintained at a constant temperature, a group of such cells could provide a uniform reference voltage (about 1.018 V) within a few microvolts.

Until January 1990, the actual value of the volt was derived from the basic SI units of length, mass, time, and electric current. Even after that date, most users maintained their voltage references in the form of electrochemical cells. The great care needed to maintain Weston cells at constant temperature and to avoid mechanical disturbance made the shipment of these devices for calibration a complex and time-consuming process. In its *Calibration Services Users Guide*, NIST recommended the use of

[25] Forest K. Harris, Electrical Measurements (New York: John Wiley & Sons, 1952), p. 185. The Weston cell is also described in *NBS Monograph 84*, by Hamer.

thermoregulated containers maintained in an upright position for transporting the cells, with a minimum of one week given to stabilizing the cell at NBS, followed by a month of measurements to achieve voltage uncertainties of 1 ppm.[26] Often, the cells were transported to NBS by courier.

Superconductive Volt Standard

Both Weston cells and Thomas resistors provided standards known as *artifacts*—each copy yielding a slightly different value of the intended quantity, depending upon the workmanship exercised by the maker and the care taken by the user.

The prediction in 1962 of a superconductive tunneling effect by Brian Josephson of Cambridge University in England markedly changed the situation for the voltage standard. Josephson received the 1973 Nobel Prize in physics for his theoretical prediction that the flow of electrons between two superconductors connected by a thin insulating layer would be quantized according to the applied voltage. It was found that when a properly prepared Josephson tunnel junction was irradiated with microwaves, its current-voltage curve would exhibit steps at precise, quantized voltages characterized by three quantities; the microwave frequency, an integer denoting the step number, and a Josephson frequency-to-voltage quotient. None of the three numbers involved the identity of the particular Josephson junction, nor even the type of materials from which it was made.

By 1985, a group of scientists from the Boulder Electromagnetic Technology Division—Clark A. Hamilton, Richard L. Kautz, and Frances L. Lloyd—had prepared a practical superconducting voltage standard at 1 V. They accomplished this feat by connecting nearly 1500 Josephson junctions made of niobium and a lead alloy in a series array, then biasing the junctions with microwaves at 72 GHz. Painstaking testing showed that the array could provide a stable reference, despite thermal cycling to room temperatures.[27] Their achievement heralded a new age for voltage standards.

Realizing the implications of the Josephson effect for voltage standards, scientists from national laboratories in Holland, England, the United States (Barry N. Taylor from NBS), and the International Bureau of Weights and Measures (BIPM) in Paris formed a working group within the framework of the BIPM to evaluate the Josephson voltage-to-frequency quotient in units consistent with the International System (SI).[28] In 1988, the International Committee of Weights and Measures suggested that the national laboratories define the value of the quotient to be 483 597.9 GHz/V, with the transition to the new voltage standard to take place on January 1, 1990.[29]

[26] Bruce F. Field, "NBS Measurement Services: Standard Cell Calibrations," *NBS Special Publication 250-24,* October 1987, 52 pp. Also see "NIST Calibration Services Users Guide, 1989," Joe D. Simmons, editor, *NIST Special Publication 250*, January 1989, pp. 114-118.

[27] C. A. Hamilton, R. L. Kautz, R. L. Steiner, and F. L. Lloyd, "Practical Josephson voltage standard at 1 V," *IEEE Electron Device Letters EDL-6,* No. 12, pp. 623-625 (1985).

[28] B. N. Taylor and T. J. Witt, "New international electrical reference standards based on the Josephson and quantum Hall effects," *Metrologia* **26**, 47-62 (1989).

[29] B. N. Taylor, "New internationally adopted reference standards of voltage and resistance," *J. Res. NIST* **94**, No. 2, 95, (1989).

DC Resistance Calibrations

With a similarly venerable history, the NBS standard of dc resistance was embodied in a group of carefully prepared wires. James L. Thomas devised a stable resistance standard for NBS during the 1930s, using bare manganin[30] wire carefully coiled in a stress-free, sealed atmosphere. A group of 1 ohm Thomas-type resistors was found invariant in resistance within 1 ppm over periods of several years.[31] Although manganin wire has a low temperature coefficient of resistivity, standard resistors were maintained as nearly as possible at a constant temperature. Since sudden bumps could induce stress-related changes in the resistance of the wires, careful handling was an important feature of resistance standards measurement.

Quantum-Based Resistance Standards

While evaluation of the Josephson voltage effect was in progress, K. von Klitzing discovered a quantum effect related to measurements of the Hall coefficient in semiconductors.[32] He found that if a high-electron-mobility semiconductor was cooled to a few kelvins above absolute zero and a magnetic field of intensity 10 T was applied to it, the two-dimensional electron gas which the system approximated became quantized. As a result, the plot of Hall voltage (at fixed current) *vs* magnetic field exhibited plateaus of resistance characterized by a constant which, like the Josephson voltage-to-frequency quotient, was independent of material parameters. The BIPM working group happily accepted the task of expressing the so-called "von Klitzing constant" in a value consistent with SI units; following their recommendation, the CIPM selected 25 812.807 Ω as the assigned value during its 1988 meeting.

At NBS, Marvin E. Cage, Ronald F. Dziuba, Bruce F. Field, Thomas E. Kiess, and Craig T. Van Degrift began use of the quantum Hall effect to monitor drift in the resistances of five Thomas resistors of 1 Ω each. The group of resistors provided NBS with its realization of the U.S. legal unit of resistance. Three different Hall-effect devices, all made from gallium arsenide, were used in the study, along with an intermediary reference resistor of 6,453 Ω. The authors found the imprecision of the measurement process to be about 0.05 ppm. Over a 31-month period, the measurements indicated that the resistance of the U.S. legal ohm was decreasing at a rate of (0.05 ± 0.02) ppm per year.[33]

There was no question that new resistance metrology would be adopted at NBS.

[30] "Manganin" is an alloy containing approximately 84 % copper, 12 % manganese, and 4 % nickel, chosen for its low temperature coefficient of resistivity and its chemical stability.

[31] Harris, op. cit., p. 213.

[32] K. v. Klitzing, G. Dorda, and M. Pepper, *Phys. Rev. Lett.* **45**, 494-497 (1980).

[33] Marvin E. Cage, Ronald F. Dziuba, Bruce F. Field, Thomas E. Kiess, and Craig T. Van Degrift, "Monitoring the U.S. legal unit of resistance via the quantum Hall effect," *IEEE Trans. on Instrum. and Meas. IM-36,* No. 2, 222-225 (1987).

Voltage and Resistance Calibrations

As might have been expected, convincing NBS/NIST customers (and their counterparts in other countries) of the wisdom of accepting a change in the volt and the ohm for any reason—let alone on the basis of quantum physics—was a challenging task as well.[34] Prior to the introduction of the 10 V array discussed below, Clark Hamilton, Charles Burroughs, and Kao Chieh reviewed the operation of the NIST 1 V Josephson-array volt standard, describing the physical structure of the chip on which 1500 junctions were deposited, the mounting of the chip in its cryoprobe, and the use of the array in voltage calibrations.[35]

Generally, calibrations were performed on Zener diodes rather than on Weston cells, because of the possibility of incurring current transients arising from switching within the Josephson array; typically, the uncertainty of the calibration was 0.02 ppm.

As of January 1990, the NIST volt was defined in terms of the Josephson-junction array. The calibration of voltage standards for NIST customers was discussed by Bruce F. Field.[36] An automated system incorporating a carefully chosen set of NIST electrochemical cells was used as the reference comparison. Inevitable drift in the voltage of the cells was monitored through routine comparisons with the Josephson array, using a set of Zener diodes as the intermediary. NIST's primary group of electrochemical cells drifted about 0.3 μV from July 1988 to October 1989, but the continual monitoring of the cell voltages kept the calibration process free of error from that source.

Customers for dc resistance calibrations similarly found the NIST service essentially unchanged by the quantum revolution. The NIST group of 1 Ω reference standard resistors was still used in calibrations, as were the usual working standards in the range $10^{-4}\,\Omega$ to $10^{-6}\,\Omega$.

Stabilizing Electrical Currents

Edwin R. Williams and Weston L. Tew conducted interesting electrical experiments early in the 1990s. The intent of the work was to produce a convenient source of stable electric current. In one case, they were able to reach stability levels as low as one part in 10^9 per hour using the output from a superconducting quantum interference device (SQUID) in an error feedback loop. They monitored a 10 mA test current by enclosing it in a toroidal transformer; variation in the current was detected by the SQUID as a change in magnetic field.[37]

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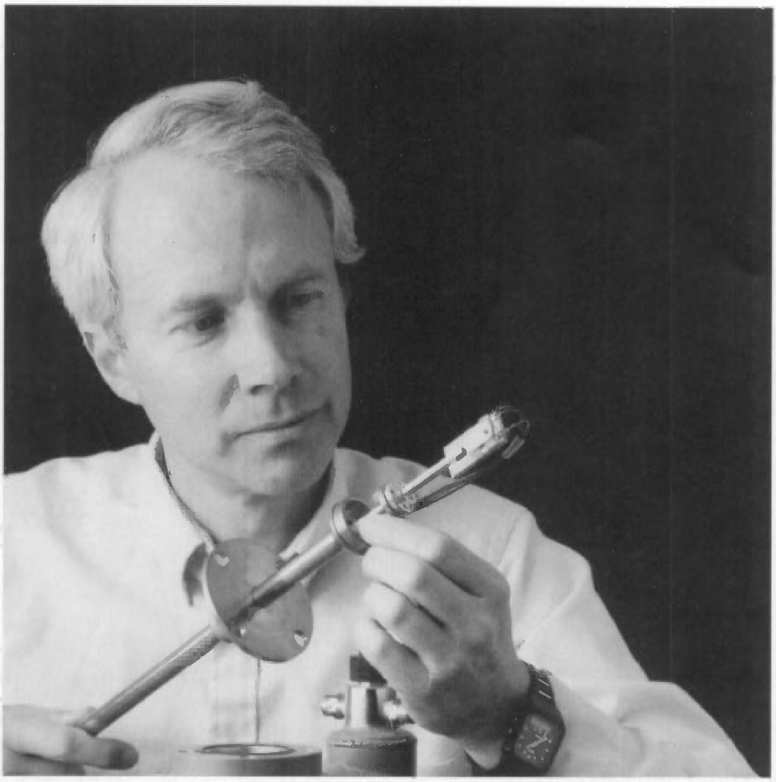
[34] K. B. Jaeger and B. N. Taylor. "U.S. perspective on possible changes in the electrical units," *IEEE Transactions on Instrumentation and Measurement,* Vol. IM-36, No. 2, pp. 672-675, June 1987.

[35] Clark A. Hamilton, Charles Burroughs, and Kao Chieh, "Operation of NIST Josephson array voltage standards," *J. Res. NIST* **95**, No. 3, pp. 219-235 (1990).

[36] Bruce F. Field, "The calibration of dc voltage standards at NIST," *J. Res. NIST* **95**, No. 3, pp. 237-253 (1990).

[37] W. L. Tew and E. R. Williams, "Flux locked current source reference," *IEEE Trans. on Instrum. and Meas.* **42**, No. 2, 186-190 (1993).



NIST electronics engineer Clark A. Hamilton examined the 1 V Josephson series array voltage standard. With about 3000 junctions, these NIST-fabricated integrated circuits are used in standards laboratories around the world.

A second study was performed by Williams and Tew with the collaboration of Cheol-Gi Kim, a guest worker from the Korea Research Institute of Standards and Science, Hitoski Sasaki, a guest worker from the Electrotechnical Laboratory in Tsukuba, Japan, and P. Thomas Olsen and S. Ye, colleagues in the NIST Electricity Division. The work featured the stabilization of a 1 A current using a nuclear magnetic resonance technique.[38] Two pairs of solenoids, co-axial and connected in tandem but magnetically opposing, produced axial fields that were nearly uniform and almost impervious to interference from steady magnetic fields outside the apparatus. The team stabilized the current in the solenoids using nuclear magnetic resonance frequency error signals derived from water samples at the center of each solenoid. Evaluation of the constancy of the test current was accomplished by monitoring the voltage across a series standard resistor with a Zener diode. The current proved stable within 0.1 ppm over an 8-hour period.

[38] C. G. Kim, E. R. Williams, H. Sasaki, W. L. Tew, S. Ye, and P. T. Olsen, "NMR based current/voltage source," *IEEE Trans. on Instrum. and Meas.* **42**, No. 2, 153-156 (1993).

Semiconductor Electronics, Frank F. Oettinger, chief

Semiconductors and Devices

Following passage of the 1988 Trade Act, the EEEL offered "cooperative research opportunities"—chances for outside organizations to work with the NIST staff—on several projects in the semiconductor electronics field. Among these were:

- Silicon characterization.
- Compound semiconductors.
- Microstructures.
- Molecular beam epitaxy.
- Thin film metrology.
- Integrated circuit metrology.
- Fault detection and prevention.
- Power electronics.

In the following paragraphs, work done in some of these projects is briefly discussed.

A Little History

W. Murray Bullis, former chief of the Electron Devices Division, illustrated the development of silicon devices and the integrated circuit industry from its beginnings, when each manufacturer had to produce its own materials, processing technology, and measurement tools. Bullis noted the many lessons learned as the industry matured and a supporting infrastructure arose to provide uniform materials, equipment, and instruments for it.[39]

Analysis of Semiconducting Films

Deane Chandler-Horowitz, Nhan V. Nguyen, Jay F. Marchiando, and Paul M. Amirtharaj collaborated with the Defense Department Advanced Projects Research Agency to analyze amorphous films of silicon carbide grown on silicon substrates. The films were considered for use as mask membranes for x-ray lithography. The Semiconductor Electronics Division team performed ellipsometric measurements on the films—a sensitive technique for the evaluation of thickness and optical properties. A two-layer analytical method provided the best fit to experimental data. In addition to layer thickness, the method was able to detect surface roughness and the presence of silicon and graphite phases.[40]

[39] W. M. Bullis, "Semiconductor measurement technology: evolution of silicon materials characterization: lessons learned for improved manufacturing," *NIST Special Publication 400/92,* July 1993, 46 pp.

[40] D. Chandler-Horowitz, N. V. Nguyen, J. F. Marchiando, and P. M. Amirtharaj, "Metrologic support for the DARPA/NRL-XRL mask program: ellipsometric analyses of SiC thin films on Si," *NISTIR 4860,* January 1993, 21 pp.

Linewidth measurement in x-ray lithography masks became slightly easier with the discovery by Michael T. Postek, Jeremiah R. Lowney, Andras E. Vladar, Robert D. Larrabee, W. J. Kerry, and Egon Marx that satisfactory contrast and good signal-to-noise ratios could be obtained using the transmitted-electron signal in a scanning electron microscope rather than the usual secondary electron signal. In the course of the work, the authors also developed a potential basis for the first SEM-based NIST linewidth standard.[41]

Nanolithography

The use of the scanning tunneling microscope to generate patterns at the nanometer level was demonstrated on III-V semiconductors such as n-doped gallium arsenide by a group that included John A. Dagata, Wing Tsang, Joseph Bennett, Jason M. Schneir, and Howard H. Haray.[42] Molecular beam epitaxy was used to prepare the substrates. They were characterized by time-of-flight secondary-ion mass spectrometry and x-ray photoelectron spectroscopy. The same authors reported a novel method for preparing GaAs substrates with markedly improved topographical and chemical surface uniformity.[43]

X-Ray Absorption

Charles E. Bouldin, G. Bunker, David A. McKeown, Richard A. Forman, and Joseph J. Ritter, of the Semiconductor Electronics Division, demonstrated that the x-ray absorption fine-structure data for the tetrahedral germanium gases $GeCl_4$, GeH_3Cl, and GeH_4 in the range 10 $(nm)^{-1}$ to 30 $(nm)^{-1}$ could be analyzed using a single scattering assumption.[44]

Electromagnetic Fields, Allen C. Newell, chief

Antenna Measurements

During this period, the NIST/Boulder Electromagnetic Fields Division staff developed an automated facility for the measurement of near-field phase and amplitude distributions from test antennas. Using the facility, they could evaluate antenna characteristics, including gain, polarization, and radiation patterns. In addition, they could obtain diagnostic information such as locating faulty elements in phased-array models, making feed adjustments, and finding surface imperfections, and they could calibrate probes.

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[41] M. T. Postek, J. R. Lowney, A. E. Vladar, R. D. Larrabee, W. J. Kerry, and E. Marx, "X-ray lithography mask metrology: use of transmitted electrons in an SEM for linewidth measurement," *J. Res. NIST* **98**, No. 4, pp. 415-445 (1993).

[42] J. A. Dagata, W. Tsang, J. Bennett, J. M. Schneir, and H. H. Haray, "Nanolithography on III-V semiconductor surfaces using a scanning tunneling microscope operating in air," *J. Appl. Phys.* **70**, No. 7, 3661-3665 (1991).

[43] J. A. Dagata, W. Tsang, J. Bennett, J. M. Schneir, and H. H. Haray, "Passivation of GaAs surfaces for scanning tunneling microscopy in air," *Appl. Phys. Lett.* **59**, No. 25, 3288-3290 (1991).

[44] C. E. Bouldin, G. Bunker, D. A. McKeown, R. A. Forman, and J. J. Ritter, "Multiple scattering in the x-ray absorption near-edge structure of tetrahedral Ge gases," *Phys. Rev.* **B38**, No. 15, pp. 10816-10819 (1988).

At the same time, Arthur R. Ondrejka and Motohisa Kanda utilized a wideband time-domain reflectometer to evaluate the reflection characteristics of RF and microwave absorbers. The reflectometer consisted of an array of paired antennas, used in a difference mode to remove unwanted signals and thus to improve the instrument sensitivity. Reflection characteristics could be measured over the range 30 MHz to 1000 MHz.[45]

Results were obtained for the initial phase of a NIST study of the alignment of planar phased-array antennas using the merged-spectrum method. An Electromagnetic Fields Division group including Ronald C. Wittmann, Allen C. Newell, Carl F. Stubenrauch, Katherine MacReynolds, and Michael H. Francis developed a theory to support evaluation of the merged-spectrum technique and provided simulation examples to illustrate the calculation of near radiation fields from array and element patterns.[46] The aim of the study was to quantify the effects of errors from uncertain measurements, antenna steering, and a variety of analytic approximations.

A new standard reference source, a spherical dipole, was developed during 1991 for use with automated antenna test systems. Galen H. Koepke, L. D. Driver, Kenneth H. Cavcey, Keith Masterson, Robert T. Johnk, and Motohisa Kanda participated in the project. The instrument had the advantage that it could be characterized theoretically as well as by measurement. The radiated field was generated remotely; connections to the signal generator and control elements were made *via* an optical fiber cable. Initial data showed good agreement between field measurements and theoretical predictions.[47]

Millimeter-Wave Devices

The development of new instrumentation incorporating millimeter waves—wide band satellite communications, short range radar, and control of vehicular traffic, to name three—was traced by Gerome R. Reeve of the Electromagnetic Fields Division. Reeve noted the growth of gallium arsenide based devices to provide less expensive, higher performance circuitry, and the new features of the NIST semiconductor program intended to meet the challenge of the new technology.[48]

Electromagnetic Technology, Robert A. Kamper, chief

A 10 Volt Josephson Reference

A 10 volt reference standard involving thousands of superconducting Josephson junctions—a dream of electronic instrument makers world-wide—first became a reality at the hands of Frances L. Lloyd, Clark A. Hamilton, James A. Beall, D. Go, Ronald

[45] A. R. Ondrejka and M. Kanda, "Time-domain method for measuring the reflection coefficient of microwave absorbers at frequencies below 1 GHz," *Proc. Digest Antennas and Propagation Society Symposium, London, Ontario, June 24-28, 1991* 3, pp. 1656-1659 (1991).

[46] R. C. Wittmann, A. C. Newell, C. F. Stubenrauch, K. MacReynolds, and M. H. Francis, "Simulation of the merged spectrum techique for aligning planar phased-array antennas," *NISTIR 3981*, October 1992, 51 pp.

[47] G. Koepke, L. D. Driver, K. Cavcey, K. Masterson, R. Johnk, and M. Kanda, "Standard spherical dipole source," *NIST Technical Note 1351*, December 1991, 133 pp.

[48] G. R. Reeve, "Millimeter wave metrology at NIST," *Proc. NCSL Workshop and symposium, Albuquerque, New Mexico, August 19-22, 1991*, pp. 183-187.

H. Ono, and Richard E. Harris in the Boulder Electromagnetic Technology Division. A short time later, Hamilton and Lloyd, along with Kao Chieh, a guest scientist from the Sichuan, China, National Institute of Metrology, and Wayne C. Goeke of the Hewlett Packard Company described the operation of such an array.[49] It was composed of nearly 19,000 tiny junctions, 12 μm by 24 μm in area, formed between layers of niobium and a lead-indium-gold alloy separated by Nb_2O_5 insulators on a small chip. Radiation at 70 GHz to 100 GHz generated voltages as high as 12 V dc in the array, a signal suitable for the calibration of Zener diodes and digital voltmeters.

The achievement was a natural consequence of the landmark development described earlier (see Superconductive Volt Standard in this chapter), in which Hamilton, Kautz, and Lloyd produced a 1 V reference using a series array of some 1500 Josephson junctions.

In order to achieve the goal of operating as many as 19,000 junctions within the required specifications, the research team modified the usual fabrication process by improving the lithographic technique and by slight changes in the deposition procedure.

Using the new array to observe a Zener diode over a 5-month period, the group was able to report a drift in the Zener output of about 0.5 ppm with an imprecision less than 0.1 ppm.

Within 2 years, Richard L. Steiner and Robert J. Astalos of the Electricity Division reported the automation of a 10 V calibration system using the new array.[50] They achieved an uncertainty level of 0.02 ppm, using a commercial standard-cell scanner connected to the array, to the Zener references, and to a digital voltmeter. Key to their success were new procedures for using a programmable millimeter wave attenuator and for error checking.

The new system facilitated the calibration of up to 20 Zener diodes per day, along with occasional digital voltmeter calibrations. Self-check features caught infrequent inconsistencies arising from system flaws—some of them so slight as to escape observation by the human operators.

The new array played an important role for the Hewlett-Packard Company, materially advancing its development of a new, high-accuracy multimeter.

High-Temperature Superconductivity

Industrial interest in superconductivity perked up noticeably with the discovery that the phenomenon could exist at unbelievably high temperatures (see High-Temperature Superconductivity, Chapt. 4). No less a personage than President Ronald Reagan touched off the furor with a *Federal Conference on Commercial Applications of Superconductivity* in July 1987. Congress followed the President's lead by including

[49] Clark A. Hamilton, Frances L. Lloyd, Kao Chieh, and Wayne C. Goeke, "A 10-V Josephson Voltage Standard," *IEEE Trans. on Instrum and Meas.* **38**, No. 2. 314-316 (1989).

[50] Richard L. Steiner and Robert J. Astalos, "Improvements for automating voltage calibrations using a 10-V Josephson array," IEEE Trans. on Instrum. and Meas. 40, No. 2, 321-325 (1991).

high-temperature superconductivity among the subjects to be covered by technical reviews mandated by the Trade and Competitiveness Act of 1988. John W. Lyons was a member of the superconductivity review panel.[51]

NBS immediately became a center for research and information on high-temperature superconductivity.

By 1990, NIST scientists were studying the preparation, analysis, and properties of superconductive materials with transition temperatures as high as 110 K, well above the normal boiling point of liquefied nitrogen—a much less expensive refrigerant than liquefied helium. The NIST program involved major collaborations among scientists from the EEEL and the Materials Science and Technology Laboratory.

A NIST Materials Science group including C. K. Chiang, Winnie Wong Ng, Lawrence P. Cook, Stephen W. Freiman, N. M. Hwang, Mark Vaudin, and Michael D. Hill found that one such material, a cuprate with the improbable formula $Bi_2Sr_2Ca_2Cu_3O_x$ (often given the acronym BSCCO in technical papers), could be synthesized from an amorphous oxide. Melting the constituents in powder form at 1200 °C, the group was able to prepare a ceramic mixture containing the desired compound in crystalline form. They presented a discussion of their preparation methods, along with electrical and magnetic measurements of the superconductor, during a 1990 meeting on Advances in Materials Science and Applications of High Temperature Superconductors.[52]

Another Materials Science group consisting of Lawrence H. Bennett, Marina Turchinskaya, Lyden J. Swartzendruber, A. Roitburd, D. Lundy, Joseph J. Ritter, and Debra L. Kaiser made a detailed study of magnetic flux dynamics in BSCCO and $YBa_2Cu_3O_6$ (often shortened to YBCO or simply 123). These superconductors were Type II, and thus exhibited the general property of allowing magnetic flux to permeate the sample without driving it entirely out of the superconducting state. Bennett and his group studied the way in which the penetrating magnetic flux formed geometric patterns that changed with the magnitude and the frequency of applied magnetic fields.[53]

Structure analysis and magnetic effects in high-temperature superconductor materials could be accomplished readily through the use of neutron diffraction at the NIST reactor. One such investigation was undertaken by a group from Bell Communications Research Company—P. F. Miceli, J. M. Tarascon, P. Barboux, L. H. Greene, B. G. Bagley, G. W. Hull, and M. Giroud—in collaboration with J. J. Rhyne and

[51] "Report of the National Commission on Superconductivity," *National Commission on Superconductivity*, Washington, D.C., August 7, 1990, 76 pp.

[52] C. K. Chiang, W. Wong-Ng, L. P. Cook, S. W. Freiman, N. M. Hwang, M. Vaudin, and M. D. Hill, "Processing Bi-Pb-Sr-Ca-Cu-O superconductors from amorphous state," pp. 127-136 in *Advances in Materials Science and Applications of High Temperature Superconductors*, NASA Goddard Space Flight Center, 1991.

[53] L. H. Bennett, M. Turchinskaya, L. J. Swartzendruber, A. Roitburd, D. Lundy, J. Ritter, and D. L. Kaiser, "Flux flow and flux dynamics in high-T_c superconductors," pp. 213-229 in *Advances in Materials Science and Applications of High Temperature Superconductors*, NASA Goddard Space Flight Center, 1991.

D. A. Neumann of the Reactor Radiation Division.[54] The authors noted that the high-temperature superconductor $YBa_2Cu_{2.8}Co_{0.2}O_{6+y}$ exhibited either superconductivity at temperatures near 60 K or antiferromagnetism, depending upon details of the composition. They examined in particular the influence of the oxygen concentration in the material, using neutron diffraction to track the magnetic transitions.

Paul Rice and John M. Moreland of the Electromagnetic Technology Division employed an electron tunneling technique known as *Tunneling Stabilized Magnetic Force Microscopy* (TSMFM), a variation of the scanning tunneling microscopy developed at NBS by Russell D. Young (see New Ideas in Physics, Chapt. 3) to examine films of $YBa_2Cu_3O_{7-\delta}$. The tip of the TSMFM was made of a tiny magnetic film that flexed in response to magnetic forces on the test surface. Using it, Rice and Moreland were able to prepare images showing the presence and pattern of magnetic pinning sites on the superconducting films.[55]

One of the first problems to be faced in evaluating the electrical properties of the new superconducting materials was making good electrical contact with samples. When electrical leads were attached to the ceramic superconductors by ordinary methods such as silver epoxy or paint or indium solder, the contact resistance usually was so high as to impair or preclude sensitive measurements. NIST researcher Jack W. Ekin, working with Betty A. Blankenship and Armand J. Panson of the Westinghouse Research and Development Center, created contacts with only about 10^{-8} Ω–cm^2 resistance by sputter-depositing silver on the sample and annealing it in oxygen at 500 °C for one hour. The new technique reduced the magnitude of the usual contact resistance by about a factor of one million. The U.S. Patent Office issued a patent for the process.[56]

Along with K. Salama and V. Selvamanickam of the Texas Center for Superconductivity at the University of Houston, Ekin used his new electrical contact process to make connections to oriented YBCO crystals prior to measuring the magnitude of their critical current. The new contact method, reducing enormously the heat generated by the test currents, appeared responsible for increasing markedly the maximum attainable current densities.

At 77 K, the measured critical current density reached 8 kA/cm^2 at 8 T, three times the maximum value achieved in previous experiments. Measurable values of critical current extended to 30 T at the same temperature, well in excess of earlier results.

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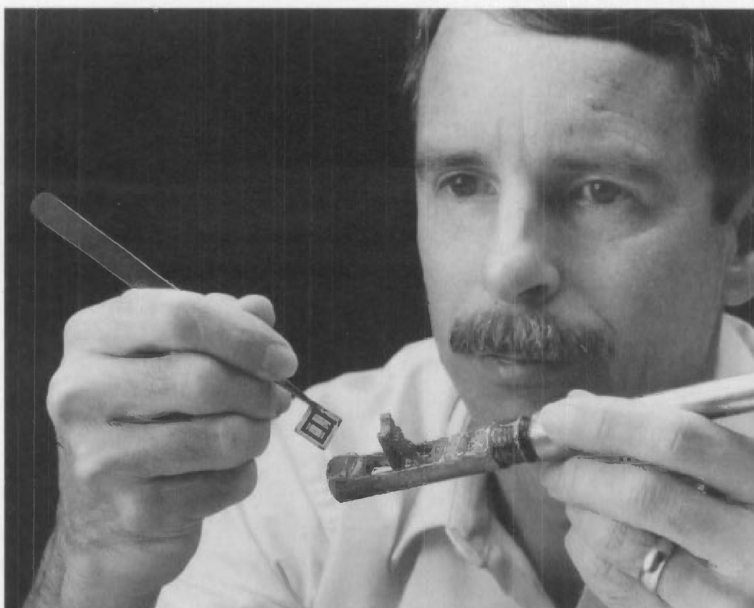
[54] P. F. Miceli, J. M. Tarascon, P. Barboux, L. H. Greene, B. G. Bagley, G. W. Hull, M. Giroud, J. J. Rhyne, and D. A. Neumann, "Magnetic transitions in the system $YBa_2Cu_{2.8}Co_{0.2}O_{6+y}$," *Phys. Rev.* **B39**, No. 16 (Rapid communications), 12375-12378 (1989).

[55] P. Rice and J. Moreland, "Tunneling Stabilized Magnetic Force Microscopy of $YBa_2Cu_3O_{7-\delta}$ films on MgO at 76 K," *IEEE Trans. on Magnetics* **27**, No. 6, 5181-5183 (1991).

[56] J. W. Ekin, A. J. Panson, and B. Blankenship, "Method for making low-resistivity contacts to high T_c superconductors," *Appl. Phys. Lett.* **52**, No. 4, 331-333 (1988). See also Collier Smith, "Low-resistance contacts developed for high-temperature superconductivity," pp. 3, 12 in "NBS Research Reports," *NBS Special Publication 735,* December 1987. See also Collier Smith, "Making Good Contact," p. 11 in NIST Research Reports, *NIST Special Publication 809,* March 1991.

The authors noted the crucial importance of high current density for many applications in superconductivity.[57]

A comparison of methods used for the evaluation of superconducting critical current—the most current that a material could carry without returning to the normal, resistive state—was undertaken by Loren F. Goodrich and Ashok N. Srivastava of the Electromagnetic Technology Division. Noting the variety of available methods to obtain critical current values, the authors outlined several of these techniques, calling attention to the advantages and disadvantages of each.[58]



A method for making improved electrical contacts to high-temperature superconductors was developed and patented by researchers at NIST and the Westinghouse Electric Corporation. Here NIST physicist Jack W. Ekin inserted a sample into a cryogenic test fixture.

[57] J. W. Ekin, K. Salama, and V. Selvamanickam, "High transport current density up to 30 T in bulk $YBa_2Cu_3O_7$ and the critical angle effect," *Appl. Phys. Lett.* **59**, No. 3, 360-362 (1991).

[58] L. F. Goodrich and A. N. Srivastava, "Comparison of transport critical current measurement methods," *Advances in Cryogenic Engineering (Materials)* **38**, 559-566 (1992).

NIST physicist Loren F. Goodrich lowered a test cryostat containing a high-current niobium-titanium superconductor into a high-field magnet for critical current testing.

Robert L. Peterson undertook an analysis of the technical and economic impact of NIST/Boulder superconductivity programs, beginning in late 1990. He accumulated data from 33 companies by means of brief questionnaires, asking whether any of eight programs had benefitted the company, and, if so, in what ways.

Peterson found that high-temperature superconductivity had led to relatively few products by 1992. Half a dozen projects had reached the prototype stage—connectors among semiconductor chips, microwave devices, magnetic bearings and shielding, motors, and infrared detectors, for example, but the economic impact of these projects was minimal.[59]

[59] Robert L. Peterson, "An analysis of the impact on U.S. industry of the NIST/Boulder superconductivity programs: an interim study," *NISTIR 5012*, November 1993, 29 pp.

Manufacturing Engineering Laboratory

The Manufacturing Engineering Laboratory was created during the reorganization approved in January 1991 (see Taking Charge earlier in this chapter). John A. Simpson and his deputy Richard H. F. Jackson founded the laboratory on the marriage of state-of-the-art dimensional measurements and the needs of the U.S. manufacturing industry—the premise that had led, years before, to the Automated Manufacturing Research Facility.[60] Simpson retired in April 1993 after a scientific career that included 45 years' service to NBS/NIST. Robert Hocken, until 1989 chief of the Precision Engineering Division, left NIST to accept an engineering professorship at the University of North Carolina at Charlotte. The rest of the MEL management team remained intact throughout the tenure of John Lyons.

The Manufacturing Engineering Laboratory offered unique facilities and expertise in a variety of technical areas that U.S. industry needed to upgrade its products and processes. The Automated Manufacturing Research Facility continued as a star performer for the laboratory, but scientific competence was highly visible throughout its divisions—Precision Engineering, led by Dennis A. Swyt; Automated Production Technology, under Donald S. Blomquist; Robot Systems, headed by James S. Albus; and Factory Automation Systems, with Howard M. Bloom as chief. The achievements of the scientists and engineers in these divisions were manifold.

Precision Engineering, Dennis A. Swyt, chief

A Molecular Measuring Machine

A major project in NIST's precision engineering area was the development of a measuring machine intended to operate on an atomic scale. E. Clayton Teague, veteran of nearly two decades of experimentation on metallic surfaces, led the project. If all went well, the new instrument, dubbed the Molecular Measuring Machine (M^3), would be able to position itself accurately within a few atomic diameters over an area of about 25 cm^2, and to detect changes in surface topography at the same level. Heart of the M^3 would be a scanning tunneling microscope (STM) to observe surface characteristics, laser interferometry to accurately position the STM probe, and a carefully designed mounting system to provide smooth motion and isolation from the bumpy world surrounding the new tool. By 1993, the noise limit of the M^3 interferometer optics and electronics system was less than 0.1 nm, well within the design specification, although the instrument had not yet achieved overall atomic resolution.

Coordinate Measuring Machines

Under Ralph C. Veale, the dimensional metrology group completed installation of a coordinate measuring machine capable of detecting position at the 1 μm level. Such machines—though not equally capable—were becoming more and more noticeable in

[60] Former Director John Lyons recalled the vital role played by the U.S. Navy and other Federal agencies in funding the AMRF at its inception. Without such aid, the program might well have foundered.

the planning of the manufacturing industries. The group developed several Standard Reference Materials to be used in the testing and calibration of coordinate measuring machines, and collaborated on measuring machine research with a number of industrial firms.

Measuring Surface Roughness

Responding to increased industrial need for smooth surface texture, Jun-Feng Song—in 1991 a guest researcher from the ChangCheng Institute of Metrology and Measurement in Beijing, China—and Theodore V. Vorburger—leader of the division's surface metrology group—reviewed the use of standard reference samples in controlling the quality of product surfaces. They noted disagreements as large as 50 % among measurements made by different methods for profiling surfaces—contact, optical, and electron tunneling techniques. In many such cases, different measuring instruments simply responded to different aspects of the same surface, producing measurement results that varied accordingly. In other cases, significant variation in surface roughness, designated by the symbol R_a, occurred in different areas of the same surface. The two scientists concluded that satisfactory and reproducible manufactured surfaces could be achieved only after reaching a detailed understanding of the desired surface texture and employing reference samples consistent with that texture.[61]

With P. Rubert, of Rubert & Company, Stockport, England, the two researchers compared the R_a values derived from roughness master samples—relatively expensive to produce—with cheaper copies made by electroforming. For the test, they selected two masters with R_a values of 0.028 μm and 0.043 μm and compared measurement results, using a stylus instrument, with electroformed replica surfaces. The agreement between the two surfaces was good—fluctuations in master R_a values repeated on the copies within 1.8 nm. This was good news, as it boded well for more extensive use of the technique with less expensive reference surfaces. Flatness reproduction and hardness was noticeably poorer in the replicas, however.[62]

Vorburger, Joseph Fu, and Russell D. Young adapted a scanning tunneling microscope (STM) for longer-range scanning. They were able to extend its field of view to an area 0.5 mm by 0.5 mm. They accomplished the improvement by mounting the specimen on a traveling stage while holding the STM probe stationary in the plane of the stage. The probe mapped the topological features of the specimen by scanning within a range of 0.008 mm in the direction perpendicular to the plane of the stage.[63]

[61] J.-F. Song and T. V. Vorburger, "Standard reference specimens in quality control of engineering surfaces," *J. Res. NIST* **96**, No. 3, 271-289 (1991).

[62] J.-F. Song, T. V. Vorburger, and P. Rubert, "Comparison between precision roughness master specimens and their electroformed replicas," *Precision Engineering* **14**, No. 2, 84-90 (1992).

[63] J. Fu, R. D. Young, and T. V. Vorburger, "Long-range scanning for scanning tunneling microscopy," *Rev. of Sci. Instrum.* **63**, No. 4, 2200-2205 (1992).

Calibrating Optical Microscopes

Carol F. Vezzetti, Ruth N. Varner, and James E. Potzick completed a family of photomask linewidth standards for use with optical measuring microscopes. An antireflecting chromium linewidth standard, SRM 473, joined SRMs 475 and 476 as an optical microscopy reference set. The new standard was expected to be most helpful for measuring linewidths in the range 500 nm to 3000 nm, often required in the production of integrated circuits. Such measurements were difficult with optical microscopes because of the similarity of the linewidth dimension to the wavelength of the light used to make the measurement. The team recommended procedures for use of the standard to minimize edge effects in photomask measurements.[64]

Automated Production Technology, Donald S. Blomquist, chief

Error Compensation in Machine Tools

Researchers in the Automated Production Technology Division made use of the NIST computer-vision capability to help turning-machine operators reduce manufacturing errors in "real time." G. Nobel, M. Alkan Donmez—leader of the sensor systems group—and R. Burton developed a method to compensate for changes in the geometry of a cutting-machine tool while a part was being formed. They accomplished this feat by utilizing the output of a tool-inspection system to determine the magnitude of deviations from the nominal circular shape of the cutting edge. The system relied on visual observation of the tool while it was in use. Feeding the visual output to the control computer, they were able to modify the position of the tool to reduce cutting errors. Inspection of completed parts on a coordinate measuring machine showed substantial improvement in cutting performance.[65]

Somewhat later, Donmez, Kenneth W. Yee, and Bradley Damazo wrote a 50-page dissertation summarizing then-current methods for error compensation in machine tools. The major cutting errors, they said, arose from geometric relationships between the machine and the workpiece, and from heat generated during the cutting process. Geometric errors were caused by unexpected motions of machine elements—carriages, spindles, and work tables—due to imperfect machine construction and misalignments during its assembly. Thermal errors arose from gradients created by tool cutting friction and by drive motors; uneven thermal expansion caused relative displacement of the tool with respect to the workpiece.

The authors presented a generalized approach to error compensation based on the prediction of both geometric and thermally induced errors, using the control software to implement corrections. They identified more than 30 error components, although they pointed out that not all machines would necessarily exhibit all types of error.[66]

[64] C. F. Vezzetti, R. N. Varner, and J. E. Potzick, "Antireflecting-chromium linewidth standard, SRM 473, for calibration of optical microscope measuring systems," *NIST Special Publication 260-119*, September 1992, 52 pp.

[65] G. Nobel, M. A. Donmez, and R. Burton, "Real-time compensation for tool form errors in turning using computer vision," *Department of Energy Report DOE/OR/21584-T1*, 1990, 9 pp.

[66] M. A. Donmez, K. W. Yee, and B. Damazo, "Some guidelines for implementing error compensation on machine tools," *NISTIR 5236*, August 1993, 56 pp.

Robot Systems, James S. Albus, chief

The robotics laboratory of NIST provided a variety of challenges for its staff. A major goal, of course, was to achieve intelligent control of machines, so that they would quickly and efficiently turn out work that consistently met design specifications. To meet this goal, however, required detailed information, both on the machine itself and on its operating environment. Further, the machine had to be equipped with sensors to provide it with real-time monitoring of the process it was performing.

James S. Albus, chief of the Robot Systems Division, led a group devoted to perfecting intelligent machine controls. This was a pivotal study, in the view of its proponents, because the industry-wide lack of a structured, theoretical approach to machine control resulted in relatively unsophisticated applications for robots in manufacturing.

The controls research project emphasized development of a formal theory for machine control, with testing facilities in which matching hardware could be coupled with the new instructions for trial and demonstration.

By 1993, a hierarchical program for machine control was in use in the division. Called the Real-Time Control System (RCS), it could be used in conjunction with job-specific control programs. The RCS program incorporated explicit software subroutines to generate machine actions, process sensor data, and assess the machine world model. Assignments in the program were decomposed by tasks, using generic subprograms to correlate machine motions. John A. Horst and Anthony J. Barbera prepared a discussion of one use of the RCS under joint sponsorship of NIST and Advanced Technology and Research, Incorporated, a local engineering firm. [67]

Another use of the Real-Time Control System hierarchy involved the Advanced Deburring and Chamfering System (ADACS). Keith Stouffer, John L. Michaloski, B. Russell, and Frederick M. Proctor described ADACS in a NIST Interagency Report.[68] In the ADACS, the machine operator was prompted by a graphical display to specify cutting parameters and edges to be chamfered on the part. The program then used the given information to configure and execute a plan for finishing the part. Sensory information was used in the cutting process to correct for small positional errors. The program was found to be successful in controlling the machining of individual parts.

Other efforts in the robotics division specialized in the processing of machine sensory data. A group under Ernest W. Kent focused on vision systems for use in real-time machine control. The team investigated both single-camera and multiple-camera systems, including scanning, non-uniform resolution, and visual input to the machine world model. Much of the sensory work dated back to 1981, when the Robotics Division—under Albus and his deputy Sidney Weiser—led the effort. Weiser, holder of several patents in the field, helped develop the first computer-controlled industrial assembly robot in 1959 while employed in industry.

[67] J. A. Horst and A. J. Barbera, "Intelligent control system for a cutting operation of a continuous mining machine," *NISTIR 5142*, March 1993, 54 pp.

[68] K. Stouffer, J. L. Michaloski, B. Russell, and F. M. Proctor, "ADACS, an automated system for part finishing," *NISTIR 5171*, April 1993, 14 pp.

Because of the cost of downtime for robotic machines, another group, led by Ronald Lumia, turned its attention to off-line programming of robots. The trouble with off-line machine programming was that the model used to generate the programs almost never matched the actual workshop environment. One approach to the mismatch problem was the extensive use of sensory information to re-form the world view of the robot when it was placed in the workshop; sometimes that technique saved days of setup time.

Yet another effort, led by Kenneth R. Goodwin, sought to develop and validate standard test procedures for measuring robot performance. An industry group, the Robot Industries Association, collaborated in the effort.

The U.S. Army had an understandable interest in mobile robots. Maris Juberts directed the NIST mobile-robot effort, which, besides the Army, included the *Intelligent Vehicle Highway System* program of the Department of Transportation. The Army wanted a standard robot-control program for a variety of labor-saving applications; the DoT wished to develop a vision-based control system for autonomous highway driving. As part of the multi-faceted study, NIST researchers developed a vision-based program for robotic maneuvering on existing roads. Test courses on the NIST/Gaithersburg grounds, on a Maryland highway, and on a closed-loop track at the Montgomery County Police Training Academy were used to demonstrate and evaluate the program. The first tests of the "traveling robot" utilized paint lines on the road for guidance. The tests were completely successful—the system proved feasible even at night.

Factory Automation, Howard M. Bloom, chief

The Factory Automation Division took as its major focus the strengthening of information systems for the manufacturing industry. Information systems helped to streamline manufacturing techniques, reducing the cost of production and enhancing product quality. A crucial first step in establishing the project was to create a standard for the sharing of product data.

One of the first activities of the division became embodied in the *Product Data Exchange Specification*. The PDES was conceived as a non-proprietary, neutral standard for the transmittal of product information among various manufacturing applications. NIST developed a software medium for the manipulation of PDES data; it was described in some detail by Stephen N. Clark. [69]

A medium developed for exchange of PDES product models was a physical file format called STEP—*Standard for the Exchange of Product Model Data.* Clark also presented an early version of STEP.[70]

A whole series of subsequent publications from the division provided details of the maturing standard. The series, mostly published in the *NIST Interagency Report* format, included numbers 4353, 4528, 4538, 4573, 4577, 4612, 4629, 4641, 4683, 4684, and 4685.

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[69] S. N. Clark, "NIST PDES toolkit: Technical fundamentals. National PDES testbed report series." *NISTIR 4335*, November 1990, 34 pp.

[70] S. N. Clark, "NIST working form for STEP: National PDES testbed report series," *NISTIR 4351*, November 1990.

The PDES system was applied to the apparel industry with the collaboration of the *Defense Logistics Agency* and the *American Apparel Manufacturing Association*. The short-term goal of the project was to develop a neutral data format for exchanging two-dimensional pattern data between two apparel computer-aided-design systems.

Chemical Science and Technology Laboratory

When NIST was formed from NBS, all chemical standards and research activities were incorporated into the Chemical Science and Technology Laboratory. First director of the CSTL was Harry S. Hertz, a graduate of MIT in analytical chemistry. Hertz joined NBS in 1973; by 1978, he was chief of the Organic Analytical Research Division. During 1992, Hertz became the deputy to Curt W. Reimann in the Office of Quality Programs.

Hratch G. Semerjian succeeded Hertz as CSTL director. Semerjian was trained at Brown University as a mechanical engineer. He came to NBS in 1977. An expert in combustion processes, Semerjian was named chief of the CSTL Process Measurements Division in 1991.

The program in CSTL included a wide variety of research projects gathered into eight divisions devoted to biotechnology, chemical engineering,[71] chemical kinetics and thermodynamics, inorganic analysis, organic analysis, chemical processes, surface and microanalysis, and thermophysics.

In the following pages, we provide brief synopses of projects in each of the CSTL areas.

Biotechnology, Lura J. Powell, chief

Protein Characterization

One of the first problems studied in the biotechnology area was the quantification of proteins. CSTL researchers Susan F. Stone and Rolf L. Zeisler and their colleague Glen E. Gordon, of the Department of Chemistry and Biochemistry at the University of Maryland, utilized the techniques of polyacrylamide gel electrophoresis and neutron activation analysis for the quantification studies. With these tools, they determined the amount of phosphorus associated with separated phosphoproteins by autoradiography and densitometry as a prelude to protein quantification. They found that they could measure quantities of phosphorus at levels as low as 0.2 micrograms.[72]

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[71] The Chemical Engineering Division, located on the Boulder campus, consisted of sections devoted to the study of transport processes, systems dynamics, and properties of solids. During 1993, the division was disbanded. The various research groups were reassigned to other CSTL divisions or to the Materials Science and Technology Laboratory.

[72] S. F. Stone, R. L. Zeisler, and G. E. Gordon, "Quantitative determination of proteins using polyacrylamide gel electrophoresis and neutron activation," *Trace Element Analytical Chemistry in Medicine and Biology* 5, pp. 157-166 (1988).

Another early problem tackled by the new biotechnology staff was the development of reliable biosensors. Edith S. Grabbe and Dennis J. Reeder sought to immobilize bioactive species on a substrate without simultaneously destroying its chemical activity. The first step in such a process, it seemed to Grabbe and Reeder, was to determine the structure of immobilized protein films. They decided to employ the technique of total internal reflection fluorescence to characterize layers of the protein immunoglobulin G (IgG) on thin nylon films. The two researchers studied three features of such systems: energy transfer between IgG tagged with fluorescein isothiocyanate and nylon tagged with tetramethylrhodamine isothiocyanate; binding activity, using labelled antigens; and energy transfer between labelled IgG and labelled antigens.[73]

Center for Advanced Research in Biotechnology

The Center for Advanced Research in Biotechnology (CARB) became a reality in 1984, the first major joint venture involving NBS in the biotechnology field (see *Restructuring NIST* in this chapter). As NBS became NIST in 1988, the Center received as its new director Thomas L. Poulos, professor of biochemistry at the University of Maryland. Walter J. Stevens, a veteran of 13 years at NBS as a theoretician in the field of chemical physics, was selected as associate director.

Initial research at the Center focused on five areas:

- Crystal structures of proteins, mainly by x-ray crystallography.
- Structure of proteins in solution, mainly by two-dimensional nuclear magnetic resonance spectroscopy.
- Modeling of protein structures, using a large, dedicated computer.
- Characterization of protein properties, using the methods of physical biochemistry.
- Production of proteins in quantity by means of molecular biology.

Scientists in the Center commenced their studies on the proteins ribonuclease, chymosin, cytochrome P450, and beta-lactamase, working mainly in NIST laboratories until CARB facilities were completed. The NIST scientists studied jointly with collaborators from universities, other government laboratories, and biotechnology firms.[74]

Gary Gilliland and his collaborators Alex Wlodawer of the National Cancer Institute, Joseph Nachman, a guest worker from Isreal, and Evon Windborne of the University of Maryland determined the structure of chymosin, one of the best-known commercial enzymes. The protein, used in cheese production under the name rennin, was composed of 323 amino acids. The group determined its three-dimensional structure,

[73] E. S. Grabbe and D. J. Reeder, "Characterization of adsorbed protein layers on thin nylon films with fluorescence energy transfer between protein and nylon: A method for biosensor analysis," *Proc. 4th European Conf. On the Spectroscopy of Biological Molecules, York, England, September 1-6, 1991*, pp. 321-322.

[74] John S. Makulowich, "Biotech center names top officials," pp. 20-21 in "NIST Research Reports," *NIST Special Publication 743*, October 1988.

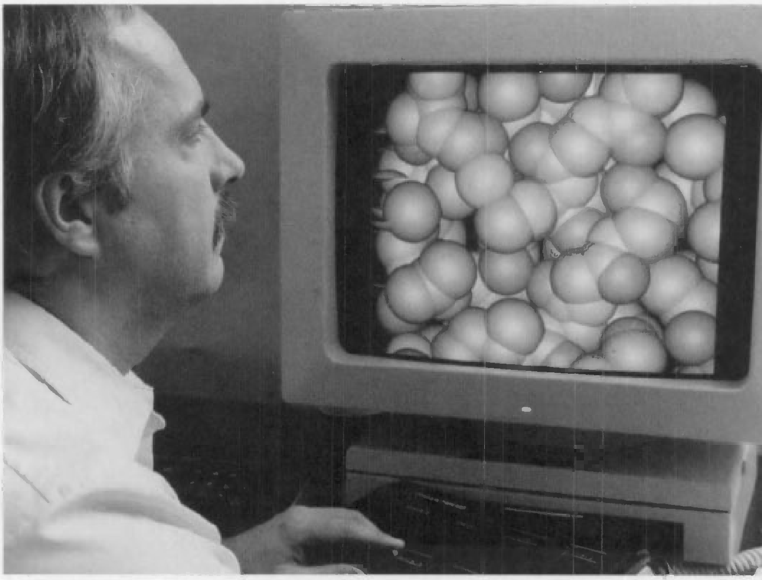
New state-of-the-art laboratory facilities for the Center for Advanced Research in Biotechnology were dedicated in November 1989 in Rockville, Maryland.

mapping the pattern with a resolution of about 0.3 nm. The work was particularly interesting because a form of chymosin was known to occur in human blood, where it played a role in regulating blood pressure.[75]

Acting NIST Director Raymond G. Kammer helped dedicate the first building on the site of the new CARB laboratories on November 29, 1989. Montgomery County, Maryland financed the construction, leasing it to a foundation associated with the University of Maryland. A memorial to Isadore M. Gudelsky, head of a family foundation that gave the 50-acre site for CARB, was dedicated at the same time. The CARB parent organization, the Maryland Biotechnology Institute (MBI) of the University of Maryland, appointed a CARB Board of Overseers headed by Donald R. Johnson of NIST. At that time, the CARB staff numbered 40 people, including 10 principal investigators drawn from NIST and MBI, 12 staff scientists and technicians, 4 post-doctoral fellows, 5 graduate students, and several visiting scientists.[76]

[75] "High-resolution structure for chymosin solved," p. 22 in "NIST Research Reports," *NIST Special Publication 743*, October 1988.

[76] Roger Rensberger, "Biotechnology research facility dedicated," pp. 16-17 in "NIST Research Reports," *NIST Special Publication 770*, January 1990.



NIST research scientist Gary Gilliland studied a model of the structure of the protein chymosin on a workstation screen at the Center for Advanced Research in Biotechnology.

By 1990, a CARB group including Keith McKenney and Prasad Reddy of NIST, and Joel Hoskins, Kalidip Choudhury, and Marc Kantorow of the University of Maryland were studying the sequencing of DNA. McKenney and Reddy focused on *E. coli*, a relatively simple, single-celled bacterium, to discover the mechanisms by which genes transcribed the genetic code into particular proteins and by which DNA molecules replicated themselves.

Chemical Engineering, Larry L. Sparks, chief

Pulse Tube Refrigerators

During the tenure of John Lyons, a group of Boulder researchers, including Wayne Rawlins, Ray Radebaugh—the group leader—Kalidip Chowdhury, James E. Zimmerman, Peter J. Storch, Lori K. Brady, and Peter E. Bradley, conducted extensive studies of cryocoolers. These small, durable devices were useful in the many situations where cooling was necessary in remote locations, or where working temperatures exceeded those provided by liquefied helium or hydrogen gases. Certain infrared detectors required a temperature environment as low as 80 K. Parametric amplifiers used in tracking satellites needed to be kept below 20 K. Cryocoolers also could be found in the semiconductor industry and cooling gamma-ray detectors in space. It was the hope of the Boulder group that cryocoolers would be useful for long-term cooling of high-temperature superconductivity products such as quantum interference devices.

At the Center for Advanced Research in Biotechnology Molecular Biology Laboratory, (in the foreground left to right) University of Maryland chemist Joel Hoskins, graduate student Kalidip Choudhury, NIST molecular biologist Dr. Keith McKenney, and graduate student Marc Kantorow examined the results of a DNA sequencing experiment.

In a 1990 paper, Radebaugh noted the development of pulse tube refrigerators—variations of the Stirling-cycle cooler. He described three types of the devices; basic, resonant, and orifice, emphasizing the evaluation—both theoretically and experimentally—of the cooler efficiency.[77] Along with Peter Storch and James Zimmerman, Radebaugh analyzed the operation of orifice pulse tube refrigerator—a difficult system to model—and compared the analysis with the results of experiments in the Boulder laboratory. Accurate prediction of the refrigeration power remained elusive, although a single-stage version of the device reached a no-load minimum temperature of 60 K, and it could remove 12 W of power at 80 K.[78]

[77] Ray Radebaugh, "A review of pulse tube refrigeration," *Advances in Cryogenic Engineering* **35**, pp. 1191-1205 (1990).

[78] Peter J. Storch, Ray Radebaugh, and James E. Zimmerman, "Analytical model for the refrigeration power of the orifice pulse tube refrigerator," *NIST Technical Note 1343*, December 1990, 86 pp.

In other work on pulse tube refrigerators, Rawlins and Radebaugh studied the performance of the regenerator portion; and Radebaugh, Chowdhury, and Zimmerman examined the effect of pulse frequency variation on the performance. Bradley and Radebaugh studied the effectiveness of regeneration in a three-stage Vuilleumier refrigerator, capable of reaching third-stage temperatures below 20 K.

Space Shuttle Engineering

Boulder cryogenic engineering researchers contributed in several ways to the NASA space shuttle program. In one project, James D. Siegwarth evaluated the performance of vortex shedding cryogenic flowmeters for use with liquid oxygen supplies to the main engines of the shuttle. Siegwarth found that the flowmeters maintained nearly their full design accuracy even though the necessary placement of the instruments was far from ideal.[79]

Siegwarth, Andrew J. Slifka, Larry L. Sparks, D. Chaudhuri, R. Compos, and T. J. Morgan obtained values of the coefficient of friction of Type 440C stainless steel over an extended range of temperature for the benefit of the space shuttle as well. The project was important to NASA as a factor in evaluating the life expectancy of bearings made of type 440C steel to be used in a high-pressure oxygen turbo-pump. In 1990, the group varied the experimental temperature from −140 °C to 350 °C and measured the sliding friction under loads from 1 GPa to 3.6 GPa and at speeds from 0.5 m/s to 2 m/s.[80] During the following year, the measurements were extended to both lower and higher temperatures.[81]

Cryogenic Fluid Flow

A number of projects on fluid flow took place during this period. A method was developed for the production of "slush" hydrogen—a mixture of liquid and solid hydrogen—by James A. Brennan, Roland O. Voth, and Paul R. Ludtke. Simplicity itself, the technique consisted of freezing hydrogen on the inside of a tube by immersing it in liquid helium (boiling point about 4 K, well below the 20 K freezing temperature of hydrogen) and rotating an augur to break up and remove the frozen particles.[82]

[79] J. D. Siegwarth, "Vortex shedding flowmeters for space shuttle main engines," *Proc. Conf. on Advanced Earth-to-Orbit Propulsion Technology, Huntsville, Alabama, May 10-12, 1988* **2**, 429-441.

[80] A. J. Slifka, J. D. Siegwarth, L. L. Sparks, and D. Chaudhuri, "Coefficient of sliding friction of 440C as a function of temperature," *NASA Conference Publication 3092* **1**, pp. 123-134 (1990).

[81] A. J. Slifka, R. Compos, T. J. Morgan, and J. D. Siegwarth, "Tribological behavior of 440C martensitic stainless steel from −184 °C to 750 °C," *Advances in Cryogenic Engineering Materials* **38**, part A, pp. 323-330 (1991).

[82] R. O. Voth, P. R. Ludtke, and J. A. Brennan, "Producing hydrogen slush with a small augur," *NASP Technical Memorandum 1099*, May 1990, 12 pp.

Brennan, Jennifer L. Scott, Charles F. Sindt, and Michael A. Lewis evaluated the effect on accuracy of cryogenic orifice flowmeters exerted by various flow conditioners. Such inserts as tubing bundles, star and Zanker conditioners, and pressure tap locations were considered in an effort to improve industry standards for the installation of orifice-type flowmeters.[83]

Thermophysical Properties of Cryogenic Fluids

An extensive, multi-purpose computer program to facilitate the availability of thermophysical data on cryogenic fluids was offered through the NIST Standard Reference Data Program from 1986.[84] Prepared by Robert D. McCarty, the program was called MIPROPS. In 1992, the program was updated and expanded by James Brennan, Daniel G. Friend, Vincent D. Arp, and McCarty. The revised program employed 32-term equations of state, augmented by equations for the ideal gas specific heat, vapor pressure *vs* temperature, melting pressure vs temperature, saturated liquid and vapor densities vs temperature, and viscosity and thermal conductivity information. In constructing the database, some 90 constants were critically evaluated for each of the 17 fluids listed below:

argon	isobutane	normal butane
carbon dioxide	carbon monoxide	deuterium
ethane	ethylene	helium
normal hydrogen	para hydrogen	methane
nitrogen	nitrogen trifluoride	oxygen
propane	xenon	

The improved program was designed to run on desktop computers, and to provide calculated values of many thermophysical properties over the range of base parameter values.[85]

Chemical Kinetics and Thermodynamics, Sharon G. Lias, chief

Combustion Kinetics

Rate constants for the unimolecular decomposition reactions and the reverse radical combination processes of four simple alkanes—methane, ethane, propane, and isobutane—were determined in 1989 by Wing Tsang.[86] The project was part of a larger program to develop a base of critically evaluated data on chemical reaction rates for combustion, sponsored by the U.S. Department of Energy.

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[83] J. L. Scott, C. F. Sindt, M. A. Lewis, and J. A. Brennan, "Effects of flow conditioners and tap location on orifice flowmeter performance," *NIST Technical Note 1352,* October 1991, 73 pp.

[84] R. D. McCarty, "Interactive FORTRAN programs for micro computers to calculate the thermophysical properties of twelve fluids (MIPROPS)," *NBS Technical Note 1097,* 1986.

[85] J. A. Brennan, D. G. Friend, V. D. Arp, and R. D. McCarty, "Computer program for computing the properties of seventeen fluids," *Cryogenics* **32**, No. 2, 212-214 (1992).

[86] W. Tsang, "Rate constants for the decomposition and formation of simple alkanes over extended temperature and pressure ranges," *Combustion and Flame* **78**, No. 1, pp. 71-86 (1989).

The temperature range covered by Tsang's study, 300 K to 1100 K, was more extensive than had previously been attempted in such a work. Consequently, he employed a more complex theoretical treatment than in previous discussions, with specific modifications for particular species. Despite his care, Tsang was not completely satisfied with the results; he was not able to find a reasonable closed form for calculating rate constants that would represent all of the experimental data. In part, the difficulty of describing the data lay in experimental inaccuracies, but more influential in Tsang's view were the complicated dependencies of the rate constants on temperature, pressure, and the nature of secondary ambient species.

For each of the alkanes studied, Tsang provided limiting high-pressure rate expressions for the decomposition and the corresponding recombinations.

In 1991, Tsang and Joseph M. Herron completed an evaluation of a database consisting of kinetic information on a number of elementary reactions involving small polyatomic molecules important to propellant combustion. The work—on which the authors spent a full year—was accomplished under the aegis of the Standard Reference Data System; it was reported in the Journal of Physical and Chemical Reference Data.[87] Both experimental and estimated data were included in the study. Data covered the temperature range from 500 K to 2500 K and the density range from 10^{17} particles per cm^3 to 10^{22} particles per cm^3. Reactions of the following species were considered: H, H_2, H_2O, O, OH, HCHO, CHO, CO, NO, NO_2, HNO, HNO_2, HCN, and N_2O.

Kinetics From Flash Photolysis Experiments

As part of a continuing study of peroxy radicals—important as reactive intermediates in combustion and in atmospheric oxidation of organic compounds—Philippe Dagaut, a guest worker from the CNRS in Orleans, France, and Michael J. Kurylo investigated the absorption spectrum and the reaction kinetics of the neopentylperoxy radical, $(CH_3)_3CCH_2O_2$.

The technique used by the researchers was gas-phase flash photolysis. They determined the absorption cross section at 298 K and 250 nm to be about 5×10^{-18} cm^2/molecule. Coupling flash photolysis with spectroscopic observation of the radical at 250 nm, they also determined the rate constant for self-reaction—chemical reaction of the radical with itself—over the range 228 K to 380 K in low-pressure nitrogen gas.

Theirs was the first spectral analysis of the neopentylperoxy radical in the measured ranges.[88]

Dagaut, Kurylo, and their colleagues Renzhang Liu of NIST and Timothy J. Wallington, a guest worker from the Ford Motor Company, also used a flash photolysis technique—involving resonance fluorescence—to obtain absolute rate constants

[87] W. Tsang and J. M. Herron, "Chemical kinetic data base for propellant combustion. I. Reactions involving NO, NO_2, HNO, HNO_2, HCN, and N_2O," *J. Phys. Chem. Ref. Data* **20**, No. 4, pp. 609-663 (1991).

[88] P. Dagaut and M. J. Kurylo, "Flash photolysis investigation of the gas phase UV absorption spectrum and self-reaction kinetics of the neopentylperoxy radical," *International J. of Chem. Kinetics* **22**, No. 11, 1177-1187 (1990).

for the gas phase reactions of hydroxyl radicals with a series of dioxanes and other cyclic ethers. The authors compared the new results with similar ones obtained for aliphatic ethers, seeking to predict the reaction rates from group reactivity values.[89]

The work was part of a larger program to study trends in the reactivity of hydroxyl radicals in the gas phase. On the basis of their investigations, the authors had developed a scale of reactivity useful for the prediction of rate constants for simple ketones, alcohols, and ethers. The hydroxyl study filled a gap in the literature, significant because of the possible role of the reactions in industrial atmospheric chemistry.

Hydroxide Thermodynamics

New experimental and theoretical data on alkaline earth monohydroxides and dihydroxides caused Malcolm W. Chase and Rhoda D. Levin to re-evaluate the relevant thermodynamic properties. Recent spectroscopic investigations had provided new values for the molecular structure, vibrational frequencies, and electronic energy levels of several hydroxides.

Early studies of magnesium dihydroxide—"milk of magnesia"—and calcium dihydroxide—"hydrated lime"—simply provided information on substances used in the daily lives of American citizens. Later studies of colors in flames led to observations on the monohydroxides of calcium, strontium, and barium. Still later, propellant investigations focused on the monohydroxides of beryllium and magnesium. Gradually, the data were organized as part of joint Army, Navy, and Air Force thermodynamic data compilations.

Chase and Levin brought up to date the information available up to 1989 on molecular structure, entropy, and enthalpy of formation of the monohydroxides of beryllium, magnesium, calcium, strontium, and barium, with emphasis on the gas phase.[90]

Estimating Thermodynamic Properties

Eugene S. Domalski and Elizabeth D. Hearing extended earlier estimation methods, used for calculating gas-phase thermodynamic properties of organic substances, to the liquid and solid phases for a variety of hydrocarbons at room temperature. One scheme in particular, derived by S. W. Benson and his colleagues over a period of years, correlated molecular structure with a corresponding energy contribution to a thermodynamic property, achieving good agreement between calculated and experimentally derived values. Domalski and Hearing used the Benson approach to estimate thermodynamic properties for liquid and solid hydrocarbons at 298.15 K. Among the properties considered were enthalpy of formation, heat capacity, and entropy.

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[89] Philippe Dagaut, Renzhang Liu, Timothy J. Wallington, and Michael J. Kurylo, "Flash photolysis resonance fluorescence investigation of the gas-phase reactions of hydroxyl radicals with cyclic ethers," *J. Phys. Chem.* **94**, No. 5, 1881-1883 (1990).

[90] Malcolm W. Chase and Rhoda D. Levin, "Thermodynamic properties of the alkaline earth hydroxides: a JANAF case history," *High Temperature Science* **26**, pp. 207-214 (1990).

The two researchers made some 1300 comparisons between theory and experimentally derived quantities. The differences were scarcely larger than the uncertainty values often reported with experimental data, demonstrating the versatility of the Benson approach.[91]

In a later investigation, Domalski and Hearing carried the method to the liquid and solid phases of organic compounds containing the elements carbon, hydrogen, oxygen, sulfur, and the halogens. Comparisons between literature values of thermodynamic properties and estimated values were obtained for more than 1500 compounds at 25 °C.[92]

Inorganic Analysis, James R. DeVoe, chief

Analyzing Fluorides

In 1990, fluoride glasses appeared likely to challenge silica fibers as choice materials for conveying messages via optical fibers. Theoretical calculations of the intrinsic power losses at communications wavelengths—about 2 μm—of heavy metal glasses composed of zirconium, barium, lanthanum, aluminum, and sodium fluorides indicated values as low as those of silica. To achieve low intrinsic losses, however, the fluoride glasses had to be nearly free of interfering impurities such as divalent iron, copper, cobalt, nickel, and neodymium—perhaps at the picogram-per-gram level. A second caution was the possible presence of scattering centers such as oxides and oxyfluorides.

In order to prepare fluoride glasses with the extreme purity levels indicated by the calculations, it was crucial that analytical methods be developed to detect specific impurities at the requisite levels. A research team composed of members from NIST—Ellyn S. Beary, Paul J. Paulsen, and T. C. Rains—and from the U.S. Naval Research Laboratory—K. J. Ewing, J. Jaganathan, and I. Aggarwal—devised chemical preparative techniques and selected sensitive analytical instruments that appeared capable of preparing and analyzing fluoride glass samples at the required impurity levels. Following the line of reasoning taken by the group indicates the state of materials preparation and analysis characteristic of that period.

First to be considered was the use of a "clean room" to minimize contamination of the glass blanks by particulate matter in the originating laboratory. Such a facility was available on the NIST Gaithersburg site. Use of quartz or teflon laboratory vessels was preferred over ordinary glassware or plastics. Reagent-grade chemicals were purified with respect to some 37 elements to the part-per-billion level or better.

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[91] E. S. Domalski and E. D. Hearing, "Estimation of the thermodynamic properties of hydrocarbons at 298.15 K," *J. Phys. Chem. Ref. Data* **17**, pp. 1637-1678 (1988).

[92] E. S. Domalski and E. D. Hearing, "Estimation of the thermodynamic properties of C-H-N-O-S-Halogen compounds at 298.15 K," *J. Phys. Chem. Ref. Data* **22**, pp. 805-1159 (1993).

The group discussed methods of glass preparation, emphasizing the care needed to obtain meaningful analytical samples to track the quality of the process.

Various analytical methods were discussed for the project, including atomic absorption spectroscopy, mass spectrometry, neutron activation analysis, and absorption loss spectrometry. In their initial laboratory efforts, the group chose atomic absorption spectroscopy coupled with electrothermal atomization in a graphite furnace (GFAAS).

Detailed examination of the NIST clean room produced measureable amounts—from less than 5 ng/g to 600 ng/g—of iron, cobalt, nickel, and copper in a hood and two ovens, with iron by far the most persistent. Similarly, measureable quantities of the same elements appeared in three NIST "ultra-pure" acids, with iron and nickel the most prevalent. Four lanthanum salts, to be used in glass preparation, yielded ng/g amounts of neodymium impurity.[93]

Clearly, preparation of "pure" fluoride glasses would be a challenge.

Analysis by Mass Spectrometry

Analysis of sulfur in steel was important for a simple reason—the toughness of certain steel formulations was known to increase rapidly as the sulfur content dropped below about 100 ppm. W. Robert Kelly, LeTian Chen—a guest scientist from the Academia Sinica in Beijing, China—John W. Gramlich, and Karen E. Hehn, recognizing the relatively poor accuracy of existing methods, attacked the steel problem using an isotope dilution technique developed at NIST for the determination of sulfur concentration.

Carefully mixing a known amount of ^{34}S with a measured amount of steel samples, the group performed thermal ionization mass spectrometry to compare the $^{34}S/^{32}S$ ratio in the spiked samples with the ratio in the original steel samples. The method proved accurate within about 3 %, considerably better than techniques used previously. An additional benefit was the determination of the sulfur content of four steel Standard Reference Materials with the same accuracy.[94]

X-Ray Analysis Program

Peter A. Pella, B. Cross, and L. Feng—a colleague from China—collaborated on improvements to computer programs for the analysis of x-ray scattering data. Influence coefficient algorithms using fundamental parametric equations for correction of inter-element effects in x-ray analysis were employed both at NIST and in analytical laboratories in China. One of these, a Chinese variation of the Comprehensive

[93] E. S. Beary, P. J. Paulsen, T. C. Rains, K. J. Ewing, J. Jaganathan, and I. Aggarwal, "Approaches to the accurate characterization of high purity metal fluorides and fluoride glasses," *J. Crystal Growth* **106**, 51-60 (1990).

[94] W. Robert Kelly, LeTian Chen, John W. Gramlich, and Karen E. Hehn, "Determination of sulphur in low sulphur steels by isotope dilution thermal ionization mass spectrometry," *Analyst* **115**, 1019-1024 (1990).

Algorithms of Lachance called the FLY-FPM program, served as the basis on which the group developed a new program for use with spectrometers that incorporated both tube and secondary targets for excitation. The new program complemented others in use at NIST.[95]

Ion Exchange Chromatography

One of the analytical techiques in common use at NIST for the characterization of Standard Reference Materials at this time was ion exchange chromatography. The principal use of the method was for the determination of non-metals such as sulfur and chlorine. William F. Koch reviewed newly developed procedures and instrumentation adapted to improve the accuracy and precision of ion chromatography, emphasizing critical features of sample preparation for the analysis of fuels, botanical, and other biological material.[96]

There were many occasions in analytical chemistry when it was important to know the chemical state of a metal rather than just its concentration. Liquid chromatography was useful for those occasions, since it could separate different chemical forms of an element. However, the dilution that accompanied the chromatographic process placed a premium on sensitive detection of the species. Gregory C. Turk, William A. MacCrehan, Katherine S. Epler, and T. C. O'Haver found that laser-enhanced ionization not only was the most sensitive method for use in flame atomic spectroscopy, but it was also well-suited to the liquid chromotographic technique. The group illustrated the method with observations on the trialkyltin compounds.[97]

Organic Analysis, Willie E. May, chief

Analyzing River Sediment

A new Standard Reference Material, SRM 1939, useful in determining the concentrations of trace organic constituents of river sediment, was developed by a group including Richard E. Rebbert, Stephen N. Chesler, F. R. Guenther, Barbara J. Koster, Reenie M. Parris, Michelle M. Schantz, and Stephen A. Wise.[98] Samples for SRM 1939, "Polychlorinated Biphenyls in River Sediment A," were collected from the Hudson River. The new standard joined SRM 1941, "Organics in Marine Sediment"—collected from Baltimore Harbor—in the SRM catalog.

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[95] L. Feng, P. A. Pella, and B. Cross, "Versatile fundamental alphas program for use with either tube or secondary target excitation," *Advances in X-Ray Analysis* **33**, pp. 509-514 (1990).

[96] W. F. Koch, "Ion chromatography and the certification of Standard Reference Materials," *J. Chromatographic Science* **27**, No. 8, pp. 418-421 (1989).

[97] G. C. Turk, W. A. MacCrehan, K. S. Epler, and T. C. O'Haver, "Laser-enhanced ionization as an element-specific detector for liquid chromotography," *Proc. 4th International Symposium on Resonance Ionization Spectroscopy and its Applications, Gaithersburg, MD, April 10-15, 1988*, pp. 327-330 (1989).

[98] Richard E. Rebbert, Stephen N. Chesler, F. R. Guenther, Barbara J. Koster, Reenie M. Parris, Michelle M. Schantz, and Stephen A. Wise, "Preparation and analysis of a river sediment Standard Reference Material for the determination of trace organic constituents," *Fresenius' J. Anal. Chem.* **342**, pp. 30-38 (1992).

The two reference materials were intended for use in marine monitoring projects (SRM 1941) and for cleanup of polychlorinated biphenyl (PCB) spills (SRM 1939). The latter reference featured certified values for three derivatives of PCB and data for some 14 other derivatives. Information was included also on chlorinated pesticides and polyaromatic hydrocarbons present in the samples. The U.S. Environmental Protection Agency supplied bulk samples collected from the Hudson River to NIST for preparation of the standard materials.

Sample preparation for SRM 1939 illustrated the realistic approach to standards that characterized scientific work at NIST. Rather than producing a synthethic river sediment for calibration of environmental monitoring instruments, NIST derived its reference standard from actual river "mud."

Step one consisted of removal from the 55-gallon samples all large debris. The liquid-solid mixture was then blended and progressively sieved to remove all particles larger than about 45 μm. The remaining sediment, about 40 kg, was sterilized by exposure to more than 3 Megarads of ^{60}Co radiation and bottled in 50 g quantities. Uniformity of particle size was ascertained to assure even distribution of PCB contamination.

Four different analytical procedures were employed to determine the amounts of various classes of organic compounds in the reference material. The use of multiple procedures satisfied the SRM certification requirement that at least two independent methods be used to evaluate specified quantities of any certified species.

By the time SRM 1939 joined the more than 1000 other reference materials in the OSRM catalog, it was without peer for the calibration of marine PCB monitors.

Examining Human Plasma

Interest within the biomedical community in the efficacy of an extract of licorice root as a cancer preventative in humans led a NIST research group to develop a new analytical method in 1991. The licorice-root derivative identified as potentially defying cancer was 18β–glycyrrhetinic acid (GRA). Basic to any cancer-related studies of the substance was accurate evaluation of its concentration in human blood plasma. Among the several existing techniques for the determination of GRA concentrations in plasma, none offered a good combination of sensitivity, accuracy, and convenience.

The research team, Jeanice M. Brown-Thomas, Richard G. Christensen, Winfred Malone, and Willie E. May of NIST, and Roland Rieger, a colleague from the University of Ulm in Germany, developed an analytical method based upon the use of high-performance liquid chromatography (HPLC). An important feature of their technique was the preparation of an internal standard, composed of an easily identified GRA acetate derivative. A measured quantity of this substance was added to the plasma samples. Extraction of the GRA and its derivative by the HPLC method was followed by ultraviolet absorbance detection at 248 nm.

The method proved sensitive to concentrations of GRA in blood at the 10 ng/g level; quantitative determinations appeared feasible at the 100 ng/g level with 10 % uncertainty.[99]

Carcinogens in Coal Tar

Coal tar, a common ingredient of urban daily life, was known to harbor many carcinogenic compounds. A Standard Reference Material, SRM 1597, "Complex Mixture of Polycyclic Aromatic Hydrocarbons (PAH) From Coal Tar," was issued by NIST in 1987 to assist in analysis of various samples of coal tar. The NIST development team, Stephen A. Wise, Bruce A. Benner, G. D. Byrd, Stephen N. Chesler, Richard E. Rebbert, and Michelle M. Schantz, had provided certification or other basic information on some 30 polycyclic aromatic compounds in preparing SRM 1597.

It was clearly advantageous to refine the analysis of the reference material, however, to analyze the numerous methyl-substituted PAH compounds. The biological activity of the isomers varied significantly, and certain of the methyl isomers were known to be more active carcinogens than the parent compounds.

To improve NIST understanding of its SRM, Stephen Wise took advantage of an opportunity to collaborate with Philippe Garrigues and Jacqueline Bellocq of the Physico-Chemical Oceanography group at the University of Bordeaux in France, who had some familiarity with the problem compounds. The group used a combination of liquid chromatography and high-resolution Shpol'skii spectroscopy—a low-temperature fluorescence technique—to determine the concentrations of 12 methyl isomers of benzopyrene, some of the most virulent of the known carcinogens. It was the first unambiguous identification and quantification of these substances in a coal tar.[100]

Chemical Processes, Hratch G. Semerjian, chief; succeeded by Gregory J. Rosasco in 1992

A New Scale of Temperature is Adopted, New Thermometry Projects Begin

The *International Temperature Scale of 1990* (ITS-90), the fifth international temperature scale since the Treaty of the Meter in 1875, was adopted by the International Committee of Weights and Measures during its meeting in 1989. Authority for the adoption had been granted by the 18th General Conference of Weights and Measures in 1987.[101] The new scale incorporated the results of numerous NBS/NIST projects in thermometry. Some of these projects were mentioned in Ch. 4, others were of more recent origin. By no means were all of the projects discussed below carried out in the Process Measurements Division—they are gathered here to give coherence to the discussion.

[99] Jeanice M. Brown-Thomas, Richard G. Christensen, Roland Rieger, Winfred Malone, and Willie E. May, "Determination of glycyrrhetinic acid in human plasma by high-performance liquid chromatography," *J. Chromatography* **568**, pp. 232-238 (1991).

[100] Philippe Garrigues, Jacqueline Bellocq, and Stephen A. Wise, "Determination of methylbenzo(a)pyrene isomers in coal tar standard reference materials using liquid chromatography and Shpol'skii spectrometry," *Fresenius J. Anal. Chem.* **336**, 106-110 (1990).

[101] H. Preston-Thomas, "The International Temperature Scale of 1990 (ITS-90)," *Metrologia* **27**, 3-10 (1990).

NIST Contributions to ITS-90

The ITS-90 was defined according to different physical principles in different ranges. Underlying all the ranges were more than a dozen reference temperatures, assigned specific values that were intended to tie the ITS-90 closely to the Kelvin thermodynamic scale. From 20 K to 1000 K, gas thermometry measurements were relied upon to provide approximate Kelvin-scale values for the defining fixed points of the ITS-90; in the range 273 K to 1000 K, the defining gas thermometry was accomplished by Leslie A. Guildner, Robert E. Edsinger, Richard L. Anderson, and James F. Schooley at NBS.

The assigned temperature of the gold freezing point was determined by Klaus D. Mielenz, Robert D. Saunders, Jr., and John B. Shumaker (see below).

Many of the devices and procedures used to create fixed-point reference temperatures in the laboratory originated in part or *in toto* at NBS/NIST. Over many years, fixed-point research was performed by a group led by George T. Furukawa. Other members of the group were William R. Bigge, John L. Riddle, and Earl R. Pfeiffer. Their investigations provided needed data on the triple points of neon, oxygen, argon, mercury, and water, and the freezing points of tin, zinc, and aluminum. Billy W. Mangum and Donald D. Thornton performed similarly successful development of gallium and indium fixed-point devices.

The defining relations in the various portions of ITS-90 were as follows:

- Between 0.65 K and 5.0 K, ITS-90 temperatures were obtained from defined relations between ^{3}He and ^{4}He vapor pressures and temperature.
- Between 3.0 K and 24.6 K (the neon triple point), ITS-90 temperatures were obtained from a gas thermometer, calibrated according to specific instructions.
- Between 13.8 K (the equilibrium hydrogen triple point) and 1235 K (the freezing point of silver), ITS-90 temperatures were obtained from defined relations between calibrated platinum resistance thermometers and temperature.
- Above 1235 K, ITS-90 temperatures were obtained from ratios of blackbody spectral radiances referred to the freezing point of silver, gold, or copper.

For the first time, the international temperature scale did not include a range defined by the electromotive force of thermocouple thermometers. High-temperature versions of the platinum resistance thermometer proved more precise all the way to the silver freezing point.

Temperature of the Freezing Point of Gold

One of the most significant measurements affecting the quality of ITS-90 in comparison to the Kelvin thermodynamic temperature scale was undertaken by Klaus D. Mielenz, Robert D. Saunders, Jr., and John B. Shumaker. In work completed just before the ITS-90 input was finalized, the NIST group offered a first-principles measurement of the freezing point of gold, an especially important reference temperature because it was often used as the basis for radiation thermometry.[102]

[102] Klaus D. Mielenz, Robert D. Saunders, Jr., and John B. Shumaker, "Spectroradiometric determination of the freezing temperature of gold," *J. Res. NIST* **95**, No. 1, 49-67 (1990).

In evaluating the gold-point temperature, the authors used a specially designed heat-pipe blackbody furnace into which they could place sizeable (about 1 kg) gold samples. They also employed a laser-irradiated integrating sphere, a prism-grating double monochromator spectroradiometer, a silicon diode detector, and an electrically calibrated radiometer. They compared the spectral radiances of the gold-point blackbody and the laser-irradiated integrating sphere at three wavelengths, then calculated the gold-point temperature from the Planck law of spectral distribution.

The gold-point freezing temperature determined by Mielenz, Saunders, and Shumaker was 1337.33 K ± 0.34 K. Theirs was the only direct spectroradiometric determination of that temperature; it was immediately incorporated as one of the basic reference temperatures of the new scale.

Calibrations on ITS-90

In order to calibrate thermometers on the new ITS-90, a number of innovations in NIST thermometry were needed:

- Christopher W. Meyer and Martin L. Reilly characterized a standard piston gage for use in calibrations throughout the range 0.6 K to 25 K, where realization of the new scale demanded vapor-pressure measurements of ^{3}He and ^{4}He and classical gas thermometry as well.[103] The authors expected to match the new scale with an imprecision no larger than 10^{-3} K.
- Gregory F. Strouse undertook a series of experiments to evaluate the consequences of non-unique definitions of temperatures in the new scale over the range 84 K to 933 K. He found that the various possible realizations of the scale provided temperature values that were identical within the measurement uncertainties of the standard platinum resistance thermometers.[104]
- Along with his colleagues Billy W. Mangum of NIST and A. I. Pokhodun and N. P. Moiseeva of the D. I. Mendeleyev Institute of Metrology in St. Petersburg, Russia, Gregory Strouse studied the characteristics of new high-temperature platinum resistance thermometers. The objective was to determine the stability of the thermometers during use at high temperatures. Some 26 thermometers of several different configurations were evaluated in the study. The importance of frequent re-calibrations during high-temperature service was clearly demonstrated by the experiments, which showed substantial (as much as 5 °C) drifts in indicated temperatures following long-term exposure to temperatures in the upper reaches of their useful ranges.[105]

[103] Christopher W. Meyer and Martin L. Reilly "Gas dependence of the effective area of the piston gage to be used for the NIST realization of the ITS-90," pp. 133-138 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, Editor.

[104] G. F. Strouse, "Investigation of the ITS-90 subrange inconsistencies for 25.5 Ω SPRTs," pp. 165-168 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor. Further information on the realization of the new scale was contained in the two papers that followed this one in the proceedings.

[105] G. F. Strouse, B. W. Mangum, A. I. Pokhodun, and N. P. Moiseeva, "Investigation of high-temperature platinum resistance thermometers at temperatures up to 962 °C, and, in some cases, 1064 °C," pp. 389-394 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

Rapid-Response Thermometers

The need to measure temperatures quickly in his new pulse-tube refrigerator—discussed earlier in this section—led Ray Radebaugh to collaborate with W. Rawlins and K. D. Timmerhaus of the University of Colorado in the design and test of a new, high-speed thermometer.[106] As a temperature sensor, the authors settled on a platinum-plated tungsten wire only 4 μm in diameter. This probe was sufficiently robust to survive high gas-flow rates, yet it responded to temperature changes with a time constant less than 0.3 ms, providing the needed 30 Hz response time.

For many years there had been a continuing need for accurate thermometry in the hot, harsh environment found inside jet aircraft engines and automobile engines. Such engines generally performed more efficiently, the higher the operating temperature. As the temperature neared the softening temperature of the engine materials, however, there was danger of catastrophic failure. Before he came to NBS in 1973 from the United Aircraft Research Laboratories, Kenneth G. Kreider was well aware of this problem. In 1992, he summarized progress on the use of durable, fast-response thermocouple thermometers for such hostile environments.[107]

For use at temperatures up to 1300 K, thermocouples made in the form of thin (about 2 μm) plates of platinum and platinum-plus-10 % rhodium, protected by various refractory alloys and oxides, proved to be capable of response times of the order of 50 μs, yet also able to survive hostile environments.

A striking new development in high-speed, high-temperature thermometry was proffered in 1983 by Raymond R. Dils of the Thermal Processes Division. Dils utilized single-crystal sapphire to carry radiation from the heated zone of a test chamber to a radiometer, providing temperature values in the range 600 °C to 2000 °C. Dils prepared the "hot" end of the sapphire rod by sputtering on it a refractory metal coating, which approximated a blackbody cavity. Over a period of years, Dils and his colleagues refined the device, achieving speed of response, wide range of temperature, and surprisingly good thermometric accuracy.[108]

For many years, a laser-based method for the determination of temperatures in gases was used to provide information on conditions in harsh environments. Designated by the acronym CARS—Coherent Anti-Stokes Raman Spectroscopy—the technique required only optical access to the gaseous environment.

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[106] W. Rawlins, K. D. Timmerhaus, and R. Radebaugh, "Resistance thermometers with fast response for use in rapidly oscillating gas flows," pp. 471-474 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

[107] Kenneth G. Kreider, "Thin-film thermocouples," pp. 643-648 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

[108] R. R. Dils, "High temperature optical fiber thermometer," J. Appl. Phys. 54, No. 3, pp. 1198-1201 (1983). See also R. R. Dils, J. Geist, and M. L. Reilly, "Measurement of the silver freezing point with an optical fiber thermometer: proof of concept," *J. Appl. Phys.* **59**, No. 4, pp. 1005-1012 (1986).

After a decade of work in which they patiently improved the accuracy of the technique at NBS/NIST, Gregory J. Rosasco, Vern E. Bean, and Wilbur S. Hurst proposed in 1990 that diatomic gases could simultaneously serve as primary standards for temperature and pressure in measurements by dynamic methods:[109]

> With modern laser diagnostic techniques, it is possible to characterize the pressure and temperature of a gas at the molecular level. The measurement times for these techniques are such that the response to changes in *T* and *P* is limited only by the fundamental relaxation and transport processes of the molecular system. This provides the basis for a new approach to the calibration of transducers used in the measurement of dynamical *P* and *T*.

The authors stated that the CARS technique permitted them to derive temperature and pressure data from measurements of the optical transitions between atomic or molecular energy levels in the gas under observation. Since the data were generated by nanosecond-length pulses from gas-volume elements of millimeter dimensions, extremely rapid and localized values of temperature and pressure could result.

Rosasco, Bean, and Hurst suggested that they could use the CARS technique to characterize the dynamic temperature and pressure profiles within, for example, a shock tube, with uncertainty levels of perhaps 5 % up to 10^8 Pa in pressure and 1500 K in temperature. These parameters represented entirely new levels of measurement capability for traditional standards.

New Thermocouple Functions

It had long been suspected (see Problems with an Unseasoned Temperature Scale in Ch. 2) that a simple quadratic function could not adequately represent the relation of the emf of standard type S thermocouples to temperature. Exhaustive experimentation demonstrated the need for higher-order reference functions. A wide-ranging collaboration produced the results, involving NIST experimenters George W. Burns, Gregory F. Strouse, and Billy W. Mangum; NIST statisticians M. Carroll Croarkin and William F. Guthrie; and experimentalist colleagues from seven other national laboratories.[110] The new functions consisted of a 9th-degree polynomial for the range –50 °C to 250 °C; another 9th-degree polynomial for the range 250 °C to 1200 °C; a 5th-degree polynomial for the range 1064 °C to 1665 °C; and a 4th-degree polynomial for the range 1664 °C to 1768 °C.

[109] Gregory J. Rosasco, Vern E. Bean, and Wilbur S. Hurst, "A proposed dynamic pressure and temperature primary standard," *J. Res. NIST* **95**, 33-47 (1990).

[110] G. W. Burns, G. F. Strouse, B. W. Mangum, M. C. Croarkin, W. F. Guthrie, P. Marcarino, M. Battuello, H. K. Lee, J. C. Kim, K. S. Gam, C. Rhee, M. Chattle, M. Arai, H. Sakurai, A. I. Pokhodun, N. P. Moiseeva, S. A. Perevalova, M. J. de Groot, Jipei Zhang, Kai Fan, and Shuyuan Wu, "New reference function for platinum-10 % rhodium versus platinum (type S) thermocouples based on the ITS-90," pp. 541-546 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

A type of thermocouple composed of gold vs platinum proved capable of precision at the level of 0.01 °C. NIST colleagues George Burns, Gregory Strouse, and Billy Mangum, in collaboration with B. M. Liu of the Shanghai Institute of Metrological Technology studied the stability of gold-platinum thermocouples and prepared reference functions for them based upon the ITS-90.[111]

Extending ITS-90 to Lower Temperatures

William E. Fogle, Robert J. Soulen, Jr., and Jack H. Colwell created a thermodynamically based temperature scale in the range 0.006 K to 0.65 K using Johnson noise thermometry, the melting curve of ^{3}He, and paramagnetic salt susceptibility.[112] They undertook their study to provide accurate thermometry for world-wide research into the properties of materials at extremely low temperatures—particularly the interesting quantum substance, ^{3}He. To construct the new scale, the authors had to bring known thermometry methods to new stages of perfection.

Expanding on initial experiments led by Robert A. Kamper and James E. Zimmerman[113] (See Thermometry with Superconductors in Ch. 2), Soulen and his colleagues spent a decade perfecting a noise thermometer based upon the use of a resistive superconducting quantum interference detector (R-SQUID). To accomplish this goal required careful circuit design and analysis, and painstaking comparison with other thermometers, including the nuclear orientation thermometer developed by Harvey Marshak (see *Nuclear Orientation Thermometry* in Ch. 4). Ultimately, the noise thermometer was considered to represent thermodynamic temperatures within an uncertainty of 0.1 % over the range 0.01 K to 0.7 K.[114]

In a similar way, the ^{3}He melting curve had to be transformed from a physics experiment into a reliable thermometer—not a primary thermometer, but an extremely useful interpolation device.[115] Using a capacitance cell borrowed from Dennis S. Greywall of the Bell Telephone Research Laboratory, a piston gauge borrowed from the NIST Pressure Group, and careful experimentation involving the R-SQUID noise thermometer mentioned earlier, the authors determined the ^{3}He melting curve (pressure vs temperature) over the range 0.005 K to 0.7 K with an uncertainty estimated at 0.1 %. The curve exhibited a minimum in pressure which the investigators utilized as a fixed point for pressure measurement.

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[111] G. W. Burns, G. F. Strouse, B. M. Liu, and B. W. Mangum, "Gold versus platinum thermocouples: performance data and an ITS-90 based reference function," pp. 531-536 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

[112] W. E. Fogle, R. J. Soulen, Jr., and J. H. Colwell, "A new cryogenic temperature scale from 6.3 to 650 mK," pp. 91-96 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

[113] R. A. Kamper and J. E. Zimmerman, "Noise thermometry with the Josephson effect," *J.Appl. Phys.* **42**, 132-136 (1971).

[114] R. J. Soulen, Jr., W. E. Fogle, and J. H. Colwell, "A decade of absolute noise thermometry at NIST using a resistive SQUID," pp. 983-988 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

[115] J. H. Colwell, W. E. Fogle, and R. J. Soulen, Jr., "The ^{3}He melting curve thermometer as a universal temperature transfer standard," pp. 101-106 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

The temperature-dependent susceptibility of the paramagnetic salt cerous magnesium nitrate—prepared in powdered form and with a portion of the cerium atoms replaced by non-paramagnetic lanthanum atoms to extend its useful range to lower temperatures—was used to provide a check on the linearity of the new scale. The authors found the scale to be linear within 0.1 % over its entire range.

The ink was barely dry on the reports of the work before Soulen, Fogle, and Colwell were deeply involved in discussions with scientists at other laboratories on questions of low-temperature physics illuminated by the new scale.

Temperatures from Radiance Measurements

A suggestion that radiance temperatures of refractory metals might serve as useful temperature references in the range 1700 K to 3700 K came from Ared Cezairliyan, Archie P. Miiller, and their colleagues Francisco Righini and Antonio Rosso from the CNR Istituto di Metrologia "G. Colonnetti." The suggestion was based on the results of an exhaustive series of experiments on 10 metals—nickel, iron, palladium, titanium, zirconium, vanadium, niobium, molybdenum, tantalum, and tungsten. The experiments showed that the radiance temperature of each element measured was constant within about 1 K, as long as all measurements were performed at a fixed wavelength. A pronounced wavelength dependence (as much as 0.5 K per nm) was found. A similar dependence was observed for the spectral emissivity of each element.[116]

NBS/NIST Gas Thermometry—An Ending and a Beginning

For a century and a half, thermometrists pursued manometer-based gas thermometry to elucidate the thermodynamic temperature scale. No other fundamental method could match the accuracy of the gas bulb, thermostat, and manometer, operated by an experienced hand over an extended range of temperatures both above and below the ice point. During this period, however, the study of traditional gas thermometry at NBS/NIST came to a halt. To take its place there arose a more modern type of gas thermometry involving acoustical resonances. It was a sea-change in a fundamental measurement area.

The End of Classical Gas Thermometry at NBS/NIST

For decades, classical gas thermometry contributed heavily to the international understanding of the thermodynamic temperature scale. NBS/NIST scientists figured prominently in this effort. With the adoption of the International Temperature Scale of 1990, however, the NIST gas thermometry project came to an end.

Classical gas thermometry was deceptively simple in its principle. The idea was to enclose a gas (the "working gas") in a bulb, measure the pressure of the working gas at some reference temperature, heat (or cool) the bulb to a temperature whose value was to be determined, and to measure the gas pressure at the new temperature. The ratio of temperatures—on the thermodynamic, or Kelvin, scale—was the same as the ratio of the measured pressures, give or take a few corrections.

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[116] A. Cezairliyan, A. P. Miiller, F. Righini, and A. Rosso, "Radiance temperature and normal spectral emissivity of metals at their melting point as possible reference values," pp. 377-382 in *Temperature, Its Measurement and Control in Science and Industry* **6**, 1992, J. F. Schooley, editor.

The principle was so simple that many a thermometrist approached gas thermometry with a light heart and a song on his lips, only to find disaster. It turned out that the two ratios were identical only within strict limits:

- The working gas had to obey the Ideal Gas Law, or deviate from it in a way that could be accounted for with great accuracy. Impurities in the working gas—a common occurence—doomed many an experiment.

- All of the working gas had to feel the same temperature, a difficult constraint whenever the temperature to be evaluated was far from the reference temperature. Gas in the tubing used to fill and empty the bulb and to measure its pressure inevitably passed through a temperature gradient, complicating the analysis of the experiment.

- The manometric pressure measurement had to be highly accurate, a difficult requirement because of the large temperature dependence of the density of mercury—the most common manometric fluid.

The ability to find and evaluate the consequence of each of the hidden, or systematic, errors in gas thermometry determined its success or failure. Over and over again, gas thermometrists felt certain that they had achieved the desired thermodynamic accuracy in their experiments. Just as frequently, subsequent measurements proved them wrong. One experiment would founder on unsuspected impurities in the working gas; another, on imperfect manometry; a third, on poor temperature equilibrium within the measurement chamber.

The National Bureau of Standards entered the gas-thermometry arena in the 1920s. Carl S. Cragoe and T. B. Godfrey, realizing the central importance of manometry to successful gas thermometry, began a project on high-accuracy pressure measurement at that time. C. H. Meyers and R. D. Thompson later made improvements to their design.[117]

Harold F. Stimson, a leader in NBS thermometry for four decades, continued the manometry project, focusing on the use of constant-volume gas thermometers with the pressure of the working gas to be measured using mercury manometry. Stimson settled on the use of gage block end standards to determine the height difference between the lower arm of the manometer and its upper arm. Using these methods and carefully isolating the experiment from thermal disturbances, Stimson achieved estimated uncertainties of ± 20 ppm in the density of the mercury, ± 10 ppm in the gravitational constant, and ± 2 ppm in the end standards.

In the late 1950s, a new team of NBS gas thermometrists was formed. The team leader was Leslie A. Guildner, trained in the science by James A. Beattie at MIT. Guildner's principal Bureau colleagues were Richard L. Anderson and Robert E. Edsinger. This team's destiny was to create the ultimate in gas thermometry, including a mercury manometer with an estimated overall uncertainty of only 1 ppm—arguably the most accurate ever constructed for its range.

[117] L. A. Guildner, H. F. Stimson, R. E. Edsinger, and R. L. Anderson, "An accurate mercury manometer for the NBS gas thermometer," *Metrologia* **6**, No. 1, pp. 1-18 (1970).

Developed on the Bureau's Connecticut Avenue site, the gas thermometry equipment reached its full potential after the move to the new Gaithersburg laboratories. The manometer was installed in a subterranean chamber of the Gaithersburg Physics building, two floors below the main laboratory and one floor below an aggressive air-handling system that regulated and measured the air temperature at the millidegree level. The gas-bulb system could be moved hydraulically from an ice bath to a stirred liquid bath without breaking any gas-handling connections. Four platinum resistance thermometers recorded the temperature of the gas bulb. Some 20 thermocouples measured the temperature distribution along the connecting tube to the manifold that controlled the initial cleanout of the bulb, its filling, and its pressure measurement. No pains were spared to minimize the errors that had deviled earlier experiments, particularly those associated with impurities in the working gas, ^4He.

The efforts put into the gas thermometer paid off when the first determinations were made of possible differences between the 1968 temperature scale and the Kelvin thermodynamic scale. Guildner and Edsinger found a difference between the two scales of 0.027 °C at 100 °C, five times larger than the estimated uncertainty of the 1968 scale at that temperature![118] From that moment on, international progress towards a new temperature scale awaited further NBS gas thermometry results.

Before Guildner retired from NBS, he and Edsinger produced gas thermometry results at temperatures as high as 457 °C, and he designed a new oven in which the experiment could be continued to 660 °C. At 457 °C, the 1968 scale appeared too high by 0.08 °C, far beyond previous estimates of its uncertainty with respect to thermodynamic temperatures.[119] Urged by the international thermometry community to continue the NBS project to its ultimate goal despite Guildner's retirement, division management asked James F. Schooley to collaborate with Edsinger to finish the work. Edsinger and Schooley published measurements from 230 °C to 660 °C in 1989.[120] In the region of temperature overlap with the earlier results, they found similar deviations between the IPTS-68 and thermodynamic temperatures, although the magnitude of the deviations appeared to be smaller than those that Guildner and Edsinger had found.

In formulating the International Temperature Scale of 1990, the Consultative Committee for Thermometry chose to use an average of the Guildner-Edsinger and Edsinger-Schooley gas thermometry results as the basis for the new scale in the range 0 °C to 660 °C.[121]

Shortly after completing their measurements on the NBS/NIST gas thermometer, both Edsinger and Schooley retired. The apparatus was never used again.

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[118] L. A. Guildner and R. E. Edsinger, *J. Res. NBS* **77A**, 383 (1973).

[119] L. A. Guildner and R. E. Edsinger, "Deviation of international practical temperatures from thermodynamic temperatures in the temperature range from 273.16 K to 730 K," *J. Res. NBS* **80A**, 703 (1976).

[120] R. E. Edsinger and J. F. Schooley, "Differences between thermodynamic temperature and t(IPTS-68) in the range 230 °C to 660 °C," *Metrologia* **26**, 95-106 (1989). See also "Back to the Basics," pp. 5-6 in "NBS Research Reports," *NBS Special Publication 735,* December 1987.

[121] R. L. Rusby, R. P. Hudson, M. Durieux, J. F. Schooley, P. P. M. Steur, and C. A. Swenson, "Thermodynamic basis of the ITS-90," *Metrologia* **28**, 9-18 (1991).

A New Range for Acoustic Thermometry

Measurements of the speed of sound in purified gases were used to determine thermodynamic temperatures in the cryogenic range for some time. Among others, Harmon Plumb and George Cataland derived a useful scale of temperature from 2 K to 20 K by means of acoustic thermometry in ^{4}He gas (see *Cryogenic Temperature Scales and Cryogenic Physics* in Ch. 1). Beginning in the late 1970s, however, Michael R. Moldover and several colleagues took acoustic thermometry into the range above room temperature, long the exclusive province of classical gas thermometry.

Instead of relying on the accurate measurement of pressure, as had Guildner, Edsinger, and many other thermometrists over a period of more than a century, Moldover sought to measure the acoustic resonance frequencies of an argon-filled sphere that could in principle be used at temperatures well above 0 °C. At vanishingly low pressures of the working gas, the thermodynamic value of a selected temperature could be calculated from the ratio of the speed of sound at that temperature to the speed of sound at a reference temperature, multiplied by the reference temperature value—usually chosen to be the triple-point temperature of water, 273.16 K.

Teaming at various times with colleagues Meyer Waxman, Martin Greenspan, James B. Mehl, J. P. M. Trusler, T. J. Edwards, Richard S. Davis, and M. B. Ewing, Moldover found that he could determine thermodynamic temperatures in this fashion with uncertainties as low as 10^{-3} K. One of the first such temperatures to be determined was the triple-point temperature of gallium.[122] A bonus in the experiments was the re-determination of the gas constant with an uncertainty of less than 2 ppm—smaller than the uncertainty found in previous measurements by a factor of five.[123]

As the spherical resonator was tested and modified to minimize or eliminate systematic problems, it appeared likely to succeed manometer-based gas thermometry as the most reliable thermodynamic thermometer in its operating range of temperature. The transition to a new technology for fundamental thermometry was complete.

Surface Chemistry and Microanalysis, Rance A. Velapoldi, chief

A Festival of Microbeam Analysis

The year 1991 marked the 25th anniversary of the Microbeam Analysis Society, an organization of industrial, academic, and government scientists devoted to the use of the electron microscope and its close relatives in analytical work. NIST staff members were prominent in the MAS: John A. Small served as Secretary to the Executive

[122] M. R. Moldover and J. P. M. Trusler, "Accurate acoustic thermometry I: the triple point of gallium," Metrologia 25, 165-187 (1988). Recently, Moldover, Christopher W. Meyer, S. J. Boyes, and A. R. H. Goodwin reported finding the presence of a "virtual leak"—probably outgassing from sealants—in the spherical resonator that modified the earlier results; this report can be found in *J. Res. NIST* **104**, No. 1, 11-46 (1999).

[123] M. R. Moldover, J. P. M. Trusler, T. J. Edwards, T. J. Mehl, and R. S. Davis, "Measurement of the universal gas constant R using a spherical acoustic resonator," *J. Res. NBS* **93**, No. 3, 85-114 (1988).

Council; Ryna B. Marinenko was one of its directors; an award to outstanding young Society scientists was named for Kurt F. J. Heinrich, by then an Honorary Member; and one of the most recent awards for outstanding authorship had been earned by a group that included Robert L. Myklebust and Dale E. Newbury.

The 1991 technical program included several contributions from NIST, which utilized only a fraction of the instrumental techniques reported during the meeting:

- "AMMS and Raman spectroscopy of metal phthalocyanine particles and films," by Robert A. Fletcher, Joseph A. Bennett, and Edgar S. Etz of NIST, together with S. Hoeft, a chemistry graduate student at Washington University in St. Louis.
- "Micro-Raman characterization of impurity phases in ceramic and thin-film samples of the Y-Ba-Cu-O high T_c superconductor," by Edgar S. Etz, T. D. Schroeder—a NIST guest scientist from Shippensberg University of Pennsylvania—and Winnie Wong-Ng.
- "A controlled-dispersion parallel-wavelength dispersive x-ray spectrometer for electron microscopy," by Charles E. Fiori, Scott A. Wight, and A. D. Romig, Jr., a colleague from the Sandia National Laboratory.
- "Electron probe compositional mapping of particles and samples with irregular surfaces," by John A. Small, David S. Bright, Robert L. Myklebust, and Dale E. Newbury.
- "Analysis of high-T_c bulk superconductors with electron microprobe compositional mapping," by Ryna B. Marinenko.
- "Scanning electron microscopy with polarization analysis: an update," by John Unguris, M. W. Hart, Robert J. Celotta, and Daniel T. Pierce.
- "Monte Carlo electron trajectory simulation of the depth sensitivity of electron backscattering," by Dale E. Newbury and Robert L. Myklebust.

Surface Science

Studies of photoinduced desorption and other chemical reactions at surfaces stemmed in part from their importance to semiconductor and energy-conversion technologies and in part from the insight they provided into surface science. Lee J. Richter, Steven A. Buntin, Daved S. King, and Richard R. Cavanagh sought information on the mechanism involved in the desorption of nitrous oxide from silicon single crystals. Irradiating a (111) silicon surface with a 1064 nm beam from a neodymium-yttrium-aluminum-garnet laser, the authors found evidence that the desorption of NO followed two different mechanisms, depending upon the extent of coverage of the surface.

The experiments were performed in an ultra-high vacuum apparatus, with the pre-cleaned silicon surface held at temperatures in the range 95 K to 100 K. Purified NO gas was introduced through capillaries placed near the crystal surface. Following laser irradiation, desorbed NO was detected by fluorescence of an optical transition in the molecule.

Evidence that the NO desorption mechanism from the (111) silicon surface varied with the extent of initial coverage appeared in a straightforward manner. The laser-induced-fluorescence signal, indicative of the number of NO molecules leaving the surface, varied by more than a factor of four as the initial exposure of the surface to NO was increased by a factor of ten. The authors offered detailed evidence that, at low NO coverage, the desorption involved a complex interaction between the silicon surface and the NO molecule.[124]

A guide to the principles and techniques important to the characterization of surfaces was provided through the publisher Plenum Press, Incorporated, by a group that included prominent present and former NBS/NIST surface scientists—Cedric J. Powell, chief of the division's Surface Spectroscopies and Standards group; Theodore E. Madey, NBS/NIST alumnus (1963-1990) then at Rutgers University; and John T. Yates, Jr., NBS alumnus (1963-1983) then at the University of Pittsburgh. Together with their colleagues Alvin W. Czanderna of the Solar Energy Research Institute of Golden, Colorado, and David M. Hercules of the University of Pittsburgh, the three served as editors of a series of tutorial books on Methods of Surface Characterization.

In "Ion Spectroscopies for Surface Analysis," Powell, Hercules, and Czanderna presented a comparison of the half-dozen major methods by which the compostion of a surface could be analyzed.[125] The techniques discussed were:

- Auger electron spectroscopy (AES).
- Ion scattering spectroscopy (ISS).
- Rutherford backscattering spectroscopy (RBS).
- Secondary ion mass spectrometry (SIMS).
- Secondary neutral mass spectrometry (SNMS).
- X-Ray photoelectron spectroscopy (XPS).

In their discussion, the authors provided comparative information on the types of particles that took part in the techniques, the extent of damage to the surface under investigation, the quantity measured in the techniques, and the depth to which the surfaces were probed. Various features of the analytical methods—factors important for data collection, detection capabilities, strong points and limitations—were provided as well.

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[124] Lee J. Richter, Steven A. Buntin, Daved S. King, and Richard R. Cavanagh, "State-resolved studies of the laser-induced desorption of NO from Si(111)7x7: Low coverage results," *J. Chem. Phys.* **96**, No. 3, pp. 2324-2338 (1992).

[125] C. J. Powell, D. M. Hercules, and A. W. Czanderna, "Comparisons of SIMS, SNMS, ISS, RBS, AES, and XPS methods for surface compositional analysis," pp. 417-437 in *Ion Spectroscopies for Surface Analysis* (New York: Plenum Press, 1991).

J. William Gadzuk prepared a discussion that incorporated various aspects of the study of molecular activity at surfaces: photoemission spectroscopy, stimulated desorption, electron energy-loss spectroscopy, and collisions between molecules and surfaces. Gadzuk focused his treatment on molecular-level modeling of time-dependent phenomena at surfaces within the framework of semiclassical wave packet dynamics, building upon earlier theoretical work by E. J. Heller.[126] Details of the modeling formalism were provided to demonstrate that a variety of surface phenomena—adsorbate photoemission line shapes, stimulated desorption distributions, resonance electron energy loss spectroscopy, and molecule surface collisions were the examples given—could be treated in the same way, using time-dependent quantum mechanics.

Thermophysics, Richard F. Kayser, chief

Replacing Chlorofluorocarbons

Scientists at NIST were well aware, during this period, that chlorofluorocarbons (CFCs) had been convicted of poking holes in the earth's protective ozone layer—sunlight freed atomic chlorine from the CFC, chlorine acted essentially catalytically to convert ozone into oxygen, and the sun's most energetic ultraviolet radiation was free to wreak biological havoc on the earth and its creatures (see Chlorofluorocarbons vs the Ozone Layer in Ch. 4). NBS/NIST was asked to help find replacements for CFCs in refrigeration and aerosols, two major uses for the offending substances.

During 1991, Graham Morrison described the NIST program in the acquisition and correlation of data on alternative refrigerants. Experimental measurements discussed by Morrison included the following:

- Saturated liquid and vapor densities and vapor pressures.
- Pressure-volume-temperature relations in the gas phase, using a Burnett apparatus.
- Compressed liquid densities to 6500 kPa.
- Vapor pressure from steady-state boiling.
- Refractive index.
- Surface tension.
- Dielectric properties.
- Ideal gas heat capacity, using the spherical acoustical resonator (described earlier in this section).

[126] J. W. Gadzuk, "Semiclassical way to molecular dynamics at surfaces," *Annual Rev. of Physical Chemistry* **39**, pp. 395-424 (1988).

Refrigerants under study (and their short-hand designations) included:

- 1,1,1,2-Tetrafluoroethane (R134a).
- 1,1-Dichloro-2,2,2-trifluoroethane (R123).
- Pentafluoroethane (R125).
- 1,1,1-Trifluoroethane (R143a).
- 1,1-Difluoroethane (R32).
- 1-Chloro-1,2,2,2-tetrafluoroethane (R124).
- 1,1-Dichloro-1-fluoroethane (R141b).
- 1,1,2,2-Tetrafluoroethane (R134).
- 1,1,2-Trifluoroethane (R143).

Three data correlation schemes were discussed by Morrison. One was based upon a modified hard-sphere equation of state. A second utilized an extension of corresponding states. And a third employed a 90-term Benedict-Webb-Rubin equation.[127]

Mark O. McLinden and David A. Didion also responded to the need for reconsideration of refrigerant working fluids. They presented a discussion of the thermodynamic basis for choosing alternative compounds which emphasized the necessity for tradeoffs among the desirable and undesirable properties of such alternatives.[128] Didion independently pursued the question of the efficiency of heating and air-conditioning equipment with the use of various mixtures of working fluids. Using thermodynamic calculations, Didion provided manufacturers of heat pumps with the opportunity of achieving as much as a 30 % increase in efficiency. He received the Department of Commerce Gold Medal Award in 1987 for his efforts.

Hot Wires for Thermal Conductivity Measurements

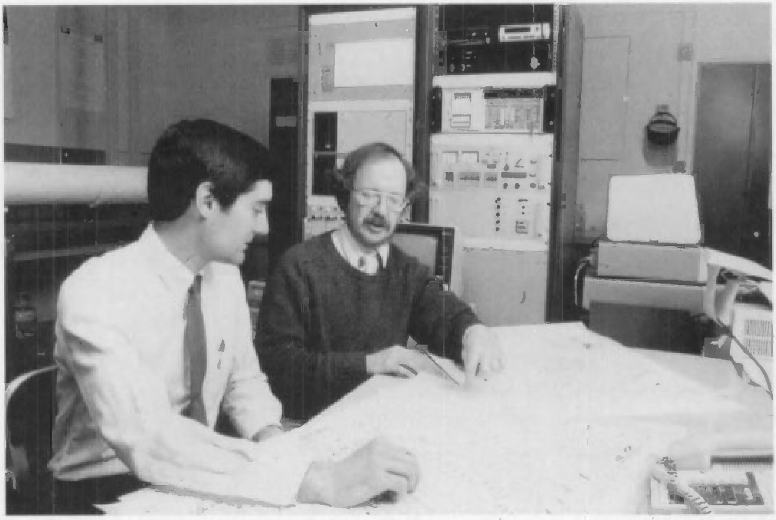
Nitrogen always was an important substance in the technology of cryogenics. As technology became more complex, the level of detail required for cryogenic fluids became more penetrating. Noting a lack of thermal conductivity and heat capacity data below room temperature, Ruth A. Perkins, Hans M. Roder, and Dale G. Friend of Thermophysics/Boulder, in collaboration with C. A. Nieto De Castro of the University of Lisbon, Portugal, undertook a series of measurements to fill some of the gaps.

In 1991, the group reported absolute measurements of the thermal conductivity and thermal diffusivity of nitrogen using a transient hot wire method. The observations, consisting of eight supercritical isotherms, three vapor isotherms, and four liquid isotherms, covered the temperature range from 80 K to 300 K and pressures up to 70 MPa.

Data were obtained with the use of a dedicated microcomputer which controlled two programmable digital voltmeters. The 1500-odd measurements included variation in the power delivered to the hot wire and variation in heating time to verify freedom from

[127] Graham Morrison, "Alternative refrigerant properties measurement and correlation program at NIST," *Pure and Applied Chem.* **63**, No. 10. 1465-1472 (1991).

[128] M. O. McLinden and D. A. Didion, "CFCs (chlorofluorocarbons): is the sky falling, Quest for alternatives," *ASHRAE Journal*, December 1987, pp. 32-42.



As part of the search for alternatives to chlorofluorocarbons, chemical engineer Mark McLinden (left) and physicist Graham Morrison developed property data for refrigerants that do not harm the ozone layer.

identifiable systematic errors and to allow calculation of thermal-difusivity and heat-capacity values with minimum measurement error. The team estimated the uncertainty in thermal conductivity determinations at ±1 % and in thermal diffusivity results at ±5 %, except for a 131 K isotherm near the critical density, where the uncertainties rose to ±3 % and ±10 %, respectively.

Correlating their data with the predictions of kinetic and other theories allowed the group to conclude that observations over a wide range of temperatures and densities would be repaid by better understanding of the thermodynamics of nitrogen.[129]

De Castro, Perkins, and Roder also evaluated the effect of radiative heat transfer in transient hot-wire thermal conductivity measurements during the same period that the work described above was in progress. They used the technique at higher temperatures—up to 548 K—so that the radiative effect would be more pronounced. Measurements on the thermal conductivity of toluene could be fitted well using heat transfer calculations that incorporated participation by the toluene in the radiative transfer process.[130]

[129] R. A. Perkins, H. M. Roder, D. G. Friend, and C. A. Nieto De Castro, "The thermal conductivity and heat capacity of fluid nitrogen," *Physica* **A 173**, pp. 332-362 (1991).

[130] C. A. De Castro, R. A. Perkins, and H. M. Roder, "Radiative heat transfer in transient hot-wire measurements of thermal conductivity," *Intl. J. of Thermophysics* **12**, No. 6, pp. 985-997 (1991).

Flowmeters for Vacuum Standards

Certain low-pressure standards required the creation of accurately known gas flow rates. Two of these concerned measurement of flow through orifices and the measurement of gaseous leak rates. Using one type of NIST standard, a calculable conductance, the operator could produce a known pressure differential by passing a gas through it at a measured flow rate. The NIST conductance standard nominally passed 10 L/s for the range 0.1 Pa and below, requiring a gas-flow reference source in the range 10^{-10} mol/s to 10^{-6} mol/s.

Kenneth E. McCulloh, Charles D. Ehrlich, Frederick G. Long, and Charles R. Tilford developed two constant-pressure piston-displacement flowmeters, either of which could be used for the orifice standard or for leak calibrations. One of the devices employed a piston with sliding seals. Its volume change and the flow rate were derived from the movement of the piston. The other, an all-metal system reaching two decades lower in flowrate, consisted of a welded bellows driven by a hydraulic press.

The group evaluated the uncertainties of the new flowmeters by considering a number of potential systematic errors—uncertainty in the reading of the pressure gage used to measure the pressure in the fixed-pressure reference chamber, volume changes during operation, temperature errors, desorption, and leakage. Over the range of usable flow rates, they estimated the uncertainties at 0.8 % to 2 %.[131]

Membrane Diffusion

Porous membranes came into increasing use during this period for purposes as diverse as blood cleansing, industrial waste recovery, and gas purification. Theorist Rosemary A. McDonald wondered whether one could predict the efficacy of filtration through a given membrane. She examined the process by means of a simple random-walk procedure, using a two-dimensional model for the membrane. She considered two types of membranes—each constructed of two sizes of pores. Spherical molecules, also of two sizes—either pure or mixed 50-50—"walked" through the membranes, sometimes under a simulated pressure head.

McDonald's results were promising in terms of predicting the diffusive nature of her simplified system. She noted, however, ". . . it is important that experimental data be available for comparison with the model results. We hope that this work may stimulate experiments along the lines we have pursued here."[132]

Vapor-Liquid Equilibrium

Increasing interest in the technology of supercritical fluids led to heavy involvement by NIST scientists in reviews of the relevant theory and applications to thermophysical properties. A 600-page text, "Supercritical Fluid Technology: Reviews in Modern

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[131] K. E. McCulloh, C. D. Ehrlich, F. G. Long, and C. R. Tilford, "Low range flowmeters for use with vacuum and leak standards," *J. Vac. Sci. and Tech. A-Vacuum Surfaces and Films* **5**, No. 3, pp. 376-381 (1987).

[132] Rosemary A. McDonald, "Modeling macromolecular diffusion through a porous medium," *J. Membrane Science* **68**, 93-106 (1992).

Richard Hyland (left) and Charles Ehrlich compared features of several calibrated leak artifacts mounted to the vacuum manifold of a new primary leak standard. Developed in the mid-1980s, the leak standard initially was used to provide calibrations for helium permeation leaks.

Theory and Applications"[133] was edited by Thomas J. Bruno and James F. Ely of the Thermophysics Division/Boulder. A listing of the titles of chapters written by NIST researchers (six of the 16 chapters in the book) gives a flavor of the topics covered:

[133] CRC Press, Boca Raton, Florida, 1991.

- "Thermodynamics of solutions near the solvent critical point," by Johanna M. H. L. Sengers.
- "Vapor-liquid equilibrium and the modified Leung-Griffiths model," by James C. Rainwater.
- "Thermophysical property data for supercritical extraction design," by Thomas J. Bruno.
- "Properties of carbon dioxide rich mixtures," by Joe W. Magee.
- "Mass transfer in supercritical extraction from solid matrices," by Michael C. Jones.
- "A summary of the patent literature of supercritical fluid technology," by Thomas J. Bruno.

Physics Laboratory

The Physics Laboratory was formed from the Center for Atomic, Molecular, and Optical Physics and the Center for Radiation Research when the new NIST organizational structure was approved in February 1991. The laboratory continued to function much as its predecessors had—as a source of new physics and new instrumentation at the leading edge of physical science. We illustrate the work of the laboratory through examples chosen from each of its eight divisions.

Physics Laboratory Office

An Update on Physical Constants

The Committee on Data for Science and Technology (CODATA), an interdisciplinary arm of the International Council of Scientific Unions, periodically published—through its Task Group on Fundamental Constants—reports summarizing worldwide progress in evaluating the large (some 38 quantities) list of fundamental physical constants.

In 1990, Barry N. Taylor and E. Richard Cohen, a physicist at the Rockwell International Science Center who customarily collaborated with Taylor on the reviews, surveyed recent advances in this field.[134] Major progress had taken place in the evaluation of the Planck constant, the fine-structure constant, and the molar gas constant. Also brought forth since the most recent (1987) CODATA report[135] were new definitions for the volt and the ohm.

[134] Barry N. Taylor and E. Richard Cohen, "Recommended values of the fundamental physical constants: a status report," *J. Res. NIST* **95**, 497-523 (1990).

[135] E. R. Cohen and B. N. Taylor, *Revs. Mod. Phys.* **59**, 1121 (1987).

It was interesting that the authors could not present new values for the re-determined quantities because to do so would require "nothing less than a new least-squares adjustment" of many of the constants previously publicized. However, they did review the so-called "auxiliary constants"—those quantities for which values were defined by international agreement or else were so accurately known as to not be subject to change by any forseeable experiments. This list included the following constants:

- Speed of light.
- Meter.
- Ratio of the proton mass to the electron mass.
- Atomic masses and mass ratios.
- Rydberg constant.
- Magnetic moment anomalies of the electron and positron.
- Ratios of the magnetic moments of the electron, the proton, and other nucleons.
- The "as-maintained" volt and ohm.
- Acceleration due to gravity.

Taylor and Cohen cited NIST work that contributed to several of these determinations.

Electron and Optical Physics, Charles W. Clark, chief

Images of Ferromagnetism

In 1990, Michael R. Scheinfein, John Unguris, Michael H. Kelley, Daniel T. Pierce, and Robert J. Celotta compared a relatively new measurement method known as SEMPA to other types of instruments that displayed the distribution of magnetization in ferromagnets.

One of the earliest field-imaging methods involved, for example, the use of fine magnetic particles that, when dusted on a magnetic surface, agglomerated in the fringe fields produced at domain walls, thus producing an image that could be viewed with an optical microscope. Another imaging technique, Lorentz microscopy, in which incident electrons were deflected by magnetic fields at the surface of the sample, could be used at low magnification (1000 nm) by beam reflection from thick samples or at high magnification (10 nm) by transmission through samples of thickness less than 300 nm. In general, transmission electron microscopy required the use of thin samples. A newer instrument, the magnetic force microscope, utilized a ferromagnetic tunneling tip to achieve resolution of domain walls at 100 nm.

SEMPA—Scanning Electron Microscopy with Polarization Analysis—achieved 10 nm resolution by detection of the polarization of secondary electrons emitted from ferromagnetic surfaces. Magnetization maps could be obtained from the surfaces of bulk specimens, thin films, and even monolayers of certain types.

In their review article, the NIST group described the individual components of their instrument—a probe forming electron optical column, a spin analyzer, transport optics, and signal-processing electronics—and they outlined the advantages and limitations of the method, including examples of images produced by its use.[136]

Illustrations of the ferromagnetic domains in an iron-silicon crystal surface showed in clear, contrasted detail the domain structure below the 10 nm level, though they were obtained in only a three-minute scan of the sample. Other illustrations portrayed domains on crystalline iron and cobalt surfaces and Permalloy ($Ni_{81}Fe_{19}$) computer memory elements, with similar clarity.

The next order of business for the NIST group was to compare the SEMPA technique with magneto-optical Kerr microscopy (MO), using measurements of surface domain-wall magnetization profiles in a Permalloy film and micromagnetic theory. With the collaboration of P. J. Ryan of Seagate Technology, Inc., they found that the two methods, substantially different in principle, produced similar domain-wall magnetization profiles (though the MO resolution was limited to about 200 nm) and similar analytical results with the use of bulk specimen parameters.[137]

Peeking at Picometers With a Scanning Tunneling Microscope

The electron physics group pursued a goal of refining the resolution of the scanning tunneling microscope (STM) on conductive surfaces. During this period, they developed the capability of routinely observing picometer-sized structures—individual atoms—on metal and semiconductor surfaces, offering seemingly endless possibilities for both science and technology.

In one example of the use of the STM at its best resolving power, Lloyd J. Whitman, Joseph A. Stroscio, Robert A. Dragoset, and Robert J. Celotta presented topographic images of the surface of an InSb (110) crystal face at the atomic level of resolution.[138] The presence of unfilled electron bonds at the surface made InSb an interesting subject for study. In the words of the authors, "... the occupied surface state density, observed when tunneling from the sample to the STM tip, is concentrated on the group-V anion, and the unoccupied state density, observed when tunneling from tip to sample, is on the group-III cation." Both tunneling directions were illustrated in the discussion.

[136] M. R. Scheinfein, J. Unguris, M. H. Kelley, D. T. Pierce, and R. J. Celotta, "Scanning electron microscopy with polarization analysis (SEMPA)," *Rev. Sci. Instrum.* **61**, No. 10, 2501-2526 (1990).

[137] M. R. Scheinfein, P. J. Ryan, J. Unguris, D. T. Pierce, and R. J. Celotta, "180° surface domain wall magnetization profiles: Comparisons between scanning electron microscopy with polarization analysis measurements, magneto-optical Kerr microscopy measurements and micromagnetic models," *Appl. Phys. Lett.* **57**, No. 17, 1817-1819 (1990).

[138] L. J. Whitman, Joseph A. Stroscio, R. A. Dragoset, and R. J. Celotta, "A scanning tunneling microscopy study of clean and Cs-covered InSb (110)," *J. Vac. Sci. Technol.* **B9**, No. 2, 770-774 (1991).

The authors obtained a clean (110) surface by cleaving the InSb crystal under high vacuum—pressure less than 10^{-8} Pa. Vertical resolution on the surface was typically 2 picometers.

Occasionally, the researchers found defects in the sample surface, which they ascribed to missing Sb atoms or to missing In and Sb pairs. These images, too, were presented in the paper.

A handsome perspective figure was formed by adsorbed Cs atoms, introduced by room-temperature deposition. The preferred modes of arrangement of the adsorbed Cs were easily seen in the image.

X-Ray Optics Characterization Facility

The capability for x-ray optics characterization at the Synchrotron Ultraviolet Research Facility (SURF-II) was described by James R. Roberts, J. Kerner, and Edward B. Saloman.[139] The 300 MeV synchrotron source provided radiation from 5 nm through the visible portion of the spectrum. A turning mirror directed the SURF beam towards a 2.2 m grazing-incidence grating monochromator and thence to a reflectometer, all within a vacuum of about 10^{-7} Pa. A sample manipulator allowed various irradiation angles and directions to be used. This feature allowed, for example, study of the response of the sample to radiation polarization.

The authors illustrated the capability of the x-ray unit with a graph showing the reflectance of a 10-layer molybdenum-silicon sample in the range 12 nm to 17 nm. The reflectance peak of the sample at the second spacing of 13.8 nm was very clearly displayed.

Ideas for improvement of the facility were presented, too. These included better use of the shortest wavelengths of the SURF radiation and improvements in the monochromator, the reflectometer, and the data-acquisition system. A multi-divisional drive to create a new beam line was funded by the Defense Advanced Research Projects Agency in 1991. Development and installation of the new hardware was the responsibility of David L. Ederer, Thomas B. Lucatorto, Robert P. Madden, and Richard N. Watts.

Theories of High-Temperature Superconductivity

The interactions underlying the phenomenon of high-temperature superconductivity were not understood in 1991, although many theorists were investigating the problem. The Bardeen-Cooper-Schrieffer (BCS) theory, so successful in accounting for most details of "ordinary" metallic superconductivity since 1957, appeared to need modifications to fit the newer oxide-superconductor properties.

David R. Penn collaborated with T. W. Barbee and Marvin L. Cohen to explore tenable theories and to explain some of the limitations that any successful theory must meet. Cohen was well-equipped for the task, having earlier predicted the occurrence of superconductivity in semiconducting materials such as $SrTiO_3$, which closely resembled the high-T_c oxides.

[139] J. R. Roberts, J. Kerner, and E. B. Saloman, "Soft x-ray optics characterization on SURF II," *Physica Scripta* **41**, pp. 9-12 (1990).

The authors suggested that simple modifications of the phonon-based BCS and Eliashberg theories might be useful, but that such modifications must accurately represent several experimental parameters of the newer superconductors, including the high superconducting transition temperatures, the relatively small isotope effect, the jump in the heat capacity at the transition temperature, and the ratio of the superconducting energy gap to the transition temperature. Historically, the presence of a strong isotope effect had been taken as evidence for the participation of phonons in the superconductive interaction, whereas the energy gap ratio and the heat capacity anomaly at the transition temperature were used to distinguish between strong-coupling and weak-coupling superconductors.

In their study, the authors focused on the established properties of several high-T_c materials, including the bismuth-strontium-calcium-copper-oxygen system, the yttrium-barium-copper-oxygen system, and the lanthanum-strontium-copper-oxygen system. They restricted their calculations to mechanisms that included at least some phonon participation, possibly in combination with electronic interactions. They pointed out that, for purely electronic mechanisms, the isotope effect would necessarily be insignificant since the ionic lattice mass would make no contribution to the superconductive interaction.

Penn and his colleagues expressed the view that neither a purely phononic nor a purely electronic mechanism was consistent with all of the existing experimental data. They postulated that a combined phonon-electron mechanism should be able to account for all the experimental results on the high-T_c materials, but confessed that, for the moment, no existing theory appeared to fit all of the experimental data.[140]

Atomic Physics, Wolfgang L. Wiese, chief

Calibrating the Hubble Space Spectrograph

Joseph Reader and Craig J. Sansonetti helped NASA calibrate the high-resolution spectrograph of the Hubble Space Telescope during 1991. The wavelength calibration for the spectrograph consisted of an atlas of some 3000 lines of the platinum-neon spectrum in the range 103.2 nm to 410 nm for use with on-board platinum lamps. Reader and Sansonetti measured the lines with a NIST 10.7 m vacuum spectrograph and used photon-counting detection to obtain relative line intensities accurate within about 20 %.

Besides the high-resolution spectrograph, the NIST results were used to calibrate the Hubble's Faint Object Spectrograph, to calibrate other satellite and rocket-borne spectrometers, and for laboratory ultraviolet spectroscopes.

A New Test of Quantum Electrodynamics

Increasingly accurate calculations and experiments in atomic and elementary particle physics provided rigorous testing of the theory of quantum electrodynamics (QED) during this period. Even more stringent tests were possible by examining the Lamb shift in two-electron systems such as helium.

[140] T. W. Barbee, III, Marvin L. Cohen, and David R. Penn, "Experimental constraints on some mechanisms for high-temperature superconductivity," *Phys. Rev.* **B44**, No. 9, 4473-4479 (1991).

Craig J. Sansonetti, John D. Gillaspy, and Chris L. Cromer took up the QED challenge by measuring the energy of the 2^1S–3^1P transition in ^4He, using Doppler-free laser spectroscopy.[141] They considered their measurement, 19931.924794 cm^{-1}, accurate within 0.000045 cm^{-1}—an order of magnitude improvement over the uncertainty of previous experiments.

Key to the success of the experiment was the careful use of up-to-date equipment and techniques. The authors created a beam of metastable helium atoms, tightly collimated to reduce the Doppler effect to a value much smaller than the width of the transition. This arrangement gave them access to the 2^1S state of helium. Radiation from a calibrated cw laser intersected the helium beam, exciting helium molecules to the 3^1P state. The process of fitting the metastable depletion curve yielded values for the line center and width. The experiment was repeated so as to generate more than 40 independent values, which averaged to the value quoted.

Comparison with QED theory was made through evaluation of the calculated Lamb shift in the binding energy of the 2^1S state in helium, which was expected to be relatively large in the NIST experiment. The authors found their result to be significantly different from the value predicted on the basis of then-current QED theory.

Atomic Spectroscopy Data

Atomic transition probabilities for the five iron-group elements—scandium, titanium, vanadium, chromium, and manganese—(some 8800 spectral lines in all) were compiled for the *Journal of Physical and Chemical Reference Data* after critical evaluation by Georgia A. Martin, Jeffrey R. Fuhr, and Wolfgang L. Wiese. The data were collated for easy reference. Separate tables were included for each element and stage of ionization, with subdivisions for allowed and forbidden transitions and a subdivision for multiplets. For each line, data included the transition probability for spontaneous emission, line strength, spectroscopic designation, wavelength, statistical weight, and the connecting energy levels.[142]

Wiese also offered a critical evaluation of emission spectroscopic experimental data on the prominent spectral lines of argon I and argon II in an effort to reduce well-known discrepancies of 30 % to 40 % in argon atomic transition probabilities. For the argon I case, the analysis was successful in reducing the discrepancies to ±5 %; Wiese reported only minimal improvement for argon II.[143]

Also during this period, William C. Martin and Wiese embarked on a new project for the benefit of all spectroscopists but especially for scientists working in astronomy and the fusion programs. The work would be incorporated into the Atomic

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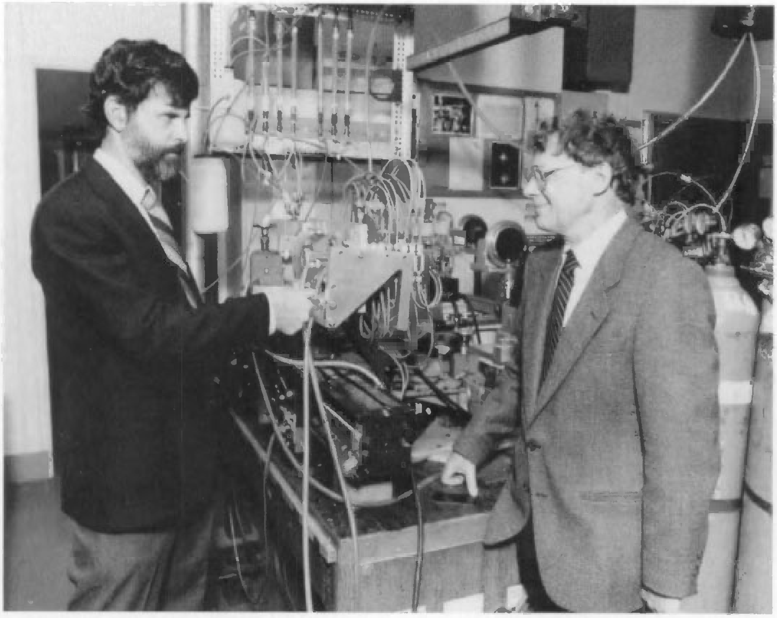
[141] Craig J. Sansonetti, J. D. Gillaspy, and C. L. Cromer, "Precise experimental test of calculated two-electron Lamb shifts in helium," *Phys. Rev. Lett.* **65**, No. 20, pp. 2539-2542 (1990).

[142] G. A. Martin, J. R. Fuhr, and W. L. Wiese, "Atomic transition probabilities scandium through manganese," Suppl No. 3, *J. Phys. Chem. Ref. Data* **17**, 1988, 531 pp.

[143] W. L. Wiese, "Atomic transition probabilities of argon: a continuing challenge to plasma spectroscopy," *J. Quantitative Spectroscopy and Radiative Transfer* **40**, No. 3, 421-427 (1988).



Jeffrey R. Fuhr (left), a physicist in the NIST Atomic Physics Division, demonstrated the wall-stabilized arc to Wolfgang L. Wiese, chief of the division. The arc is an intense source of optical radiation.

Energy Levels Data Center. Their plan was to add to a critically evaluated, digital database for spectroscopy—wavelengths, energy levels, and transition probabilities for atoms and their ions. The database was arranged for easy access by computer. Data could be retrieved in a number of ways—by species or by wavelength range, for example. Wavelengths were included from 0.1 nm to the mm range.

By 1991, spectra of multiply ionized vanadium, cobalt, and chromium and wavelengths and energy levels for aluminum and germanium had been added to the data set.

Ultraviolet Calibration for Semiconductor Processing

Mervyn J. Bridges and James R. Roberts provided special assistance to the semiconductor industry to correct a processing problem. In photolithography—the use of light to create etch patterns on semiconductors—intense ultraviolet (UV) radiation was used in conjunction with photomasks as a precursor to etching the semiconductor surface to form the patterns needed for integrated circuits. Controlling the UV exposure was accomplished by trial and error, however, for lack of adequate UV standards.

The NIST researchers characterized two types of radiometers for SEMATECH, the consortium undertaking development of the new process. Calibration of UV response and the effects of irradiation variables were included in the study, which turned up several unexpected problems with the methods then in use in photolithography. With the collaboration of scientists from the Radiometric Physics Division, Bridges and Roberts also developed a new spectroradiometer for semiconductor work.

Molecular Physics, Alfons Weber, chief

Infrared Spectroscopy of Chemical Complexes

Infrared and microwave spectroscopy of chemical complexes occupied considerable attention in the Molecular Physics Division during this period. A number of different complexes were investigated from as many different points of view.

Both infrared and microwave techniques were used by NIST scientists Gerald T. Fraser, Richard D. Suenram, Frank J. Lovas, Alan S. Pine, Jon T. Hougen, and Walter J. Lafferty in collaboration with J. S. Muenter of the University of Rochester in a study of tunneling in the dimer of acetylene.

One question asked by the group concerned the structure of the dimer and the possible presence of isomers—rarely seen in adiabatic expansion experiments. In the region of the H-C stretching fundamental, an infrared spectrum was obtained with an optothermal molecular-beam color-center laser spectrometer. A pulsed-nozzle Fourier transform microwave spectrometer was used to examine the ground state of the vibrational modes.

The authors interpreted their results as arising from a single isomer which showed internal-rotation tunneling. The wealth of spectral data yielded considerable other molecular information as well.[144]

During the same period, Fraser, Pine, and Suenram teamed with W. A. Kreiner of the University of Ulm, Germany, to obtain the infrared spectrum of the $NCH\text{-}NH_3$ complex. The team was particularly interested in the structure and dynamics of the hydrogen-bonded complex. A molecular-beam apparatus was used to form the complex by adiabatic expansion of a gas mixture of NH_3 and HCN in helium through a 40 μm diameter nozzle. The driving pressure through the nozzle was varied between 100 kPa and 300 kPa. A silicon bolometer cooled by liquid helium served as the detector.

The group obtained a rich spectrum of infrared and microwave transitions for the complex. By the use of applicable theory, these were identified with particular vibrations of the complex, including the "umbrella" mode of NH_3. Discussion of the results focused on a shift of the vibration frequency to lower values than had been seen in other NH_3 complexes.[145]

Pine and Fraser collaborated with M.–L. Junttila of the Helsinki University of Technology in Finland and J. L. Domenech of the Materials Institute in Madrid, Spain, to perform a similar experiment on benzene.[146] Since benzene, with a center of

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[144] G. T. Fraser, R. D. Suenram, F. J. Lovas, A. S. Pine, J. T. Hougen, W. J. Lafferty, and J. S. Muenter, "Infrared and microwave investigations of inter-conversion tunneling in the acetylene dimer," *J. Chem. Phys.* **89**, No. 10, pp. 6028-6045 (1988).

[145] G. T. Fraser, A. S. Pine, W. A. Kreiner, and R. D. Suenram, "Optothermal-detected microwave-sideband CO2-laser spectroscopy of NCH-NH3," *Chemical Physics* **156**, pp. 523-531 (1991).

[146] M.–L. Junttila, J. L. Domenech, G. T. Fraser, and A. S. Pine, "Molecular-beam optothermal spectroscopy of the 9.6 μm ν_{14} band of benzene," *Journal of Molecular Spectroscopy* **147**, 513-520 (1991).

symmetry, had no microwave spectrum, it was necessary to determine its ground-state rotational constants indirectly. The authors noted that experimentally determined values of these constants from different laboratories varied by larger amounts than the experimental uncertainties would warrant.

The authors were able to perform collisionless molecular-beam spectroscopy experiments on benzene. They hoped to provide high-quality calibration standards in the range around 10 μm for a variety of purposes. They used laser excitation on a benzene-helium gas vapor that was directed through a flow-controlled nozzle. Doppler shifts were minimized by crossing the laser beam and the molecular beam at nearly a right angle. They recorded spectral transitions in the ν_{14} band of benzene. This information enabled them to determine ground-state molecular constants with improved accuracy, thus reaching their goal of providing a new calibration standard.

Picosecond Energy Transfer on Surfaces

Molecular Physics Division researchers Michael P. Casassa, Edwin J. Heilweil, and John C. Stephenson teamed with John D. Beckerle and Richard R. Cavanagh of the Surface and Microanalysis Division to investigate the ultrafast exchange of energy between adsorbed gases and metallic surfaces.[147] They were able to reach picosecond time resolution by observing with infrared spectroscopy the creation and relaxation of excited states in CO molecules absorbed on a platinum single crystal. An intense picosecond laser pulse at about 2105 cm^{-1} was used to excite a stretching band in CO. Then a much weaker, time-delayed probe pulse monitored the recovery of the surface absorption.

It was the first direct measurement of the time scale of energy transfer in a vibrationally excited, ordered monolayer bound to a metal single-crystal surface. The authors discussed the results in terms of transitions from the excited band of the adsorbed CO molecules to overtone levels.

Orientation Effects in Chemical Reactions

Interest in the effects of orientation on the progress of chemical reactions led Lovas and Suenram to collaborate with scientists from three universities on a study of bimolecular gas-phase reactions. Joining the NIST researchers were C. W. Gillies of Rensselaer Polytechnic Institute, J. Z. Gillies of Union College, and E. Kraka and D. Cremer of the University of Göteborg, Sweden.

The authors took a direct approach to obtaining the orientation of the reactants in a mixture of ethylene and ozone, sampling the reacting process in a pulsed-beam nozzle. Dilute concentrations of ozone and ethylene in argon were separately fed to the high-pressure side of a pulsed solenoid valve, which served both as a flow reactor for the formation of formaldehyde as a reaction product and as a sampling device for study of the reaction. The Van der Waals complexes formed in the pulsed-nozzle expansions of 0.2 ms to 0.4 ms duration, repeated up to 10 times per second, were detected in the Fabry-Perot cavity of a Fourier-transform microwave spectrometer.

[147] J. D. Beckerle, M. P. Casassa, R. R. Cavanagh, E. J. Heilweil, and J. C. Stephenson, "Ultrafast infrared response of adsorbates on metal surfaces: vibrational lifetime of CO/Pt (111)," *Phys. Rev. Lett.* **64**, No. 17, 2090-2093 (1990).

Both microwave data and calculations were used to determine the geometry of the complex, its internal motion, and its stability. The authors were able to deduce the likely orientation of the reactants at large separations along the reaction coordinate and to estimate the stability of the Van der Waals complex involved in the reaction.[148]

Vibrational Spectra of Acetylene Ions

Ionization in planetary atmospheres of simple molecules such as acetylene was known to be an important extraterrestrial chemical process. Partly for that reason, study of acetylene and its fragments attracted the interest of Marilyn E. Jacox and two NIST guest scientists, Daniel Forney and Warren E. Thompson.[149] Earlier experiments in Jacox' laboratory had evolved a new technique for producing molecular ions trapped in solid neon; the infrared spectra of several ions, including CO^{+}_{2}, N_2O^+, and CO^+, were obtained in this fashion. Jacox and her colleagues hoped to use similar experimental methods to study $HCCH^+$.

The authors co-deposited an acetylene-neon mixture at low temperatures—about 5 K—along with neon that had been subjected to a microwave discharge. Absorption spectra of the deposits were obtained using a Fourier-transform interferometer. Further information on the materials was obtained by subjecting them to a variety of visible and ultraviolet irradiations.

Sure enough, the trio of researchers found spectral evidence that permitted the assignment of an infrared absorption to the positively charged acetylene ion, as well as a line attributed to the HCC^- fragment, detected through identification of the known CC-stretch absorption frequency. Their identification of the $HCCH^+$ cation in the neon-matrix experiments led them to postulate that the spectrum shifted strongly as a result of a change in polarizability from an argon matrix to a less-polarizable neon matrix.

In an earlier study involving a similar sampling technique but employing an argon matrix and an argon excitation source, Jacox and W. Bruce Olson had discovered an extremely complex series of absorption bands in the near infrared spectral region. They were able to show that these bands arose in the HCC fragment.[150] Only a few of these bands had been seen in the gas phase, and they corresponded closely with the HCC bands found in solid argon. Daniel Forney, Marilyn Jacox, and Warren Thompson studied these bands later using HCC and DCC trapped in solid neon. They proposed a detailed spectroscopic assignment for the band system.[151]

[148] C. W. Gillies, J. Z. Gillies, R. D. Suenram, F. J. Lovas, E. Kraka, and D. Cremer, "Van der Waals complexes in 1, 3-dipolar cycloaddition reactions: Ozone-ethylene," *J. Am. Chem. Soc.* **113**, No. 7, pp. 2412-2421 (1991).

[149] Daniel Forney, Marilyn E. Jacox, and Warren E. Thompson, "The vibrational spectra of molecular ions isolated in solid neon: $HCCH^+$ and HCC^-," *Spectroscopy* **153**, 680-691 (1992).

[150] Marilyn E. Jacox and W. Bruce Olson, "The A $^2\Pi$–X $^2\Sigma^+$ transition of HC_2 isolated in solid argon," *J. Chem. Phys.* **86**, No. 6, 3134-3142 (1987).

[151] Daniel Forney, Marilyn E. Jacox, and Warren E. Thompson, "The infrared and near-infrared spectra of HCC and DCC trapped in solid neon," *J. Molecular Spectroscopy* **170**, 178-214 (1995).

Radiometric Physics, Klaus D. Mielenz, chief, succeeded by Albert C. Parr in 1991

Absolute Cryogenic Radiometer

One of the new research tools in the Radiometric Physics Division during this period was an absolute radiometer that employed cryogenic radiation collection and energy evaluation by electrical substitution. The instrument was based upon a development of Martin L. Reilly and Defoe C. Ginnings (see Electrical Substitution Radiometry in Ch. 4) which was brought to the stage of demonstrated high-accuracy radiometry by Terence J. Quinn and John Martin of the National Physical Laboratory in England. Later, a NIST group collaborated with NPL physicists in the development of a similar instrument for the NIST radiometer calibration program. The cryogenic radiometer, operating near 5 K, incorporated smaller and simpler corrections than instruments operating at higher temperatures. Its radiometric measurement uncertainty was estimated at 0.01 %. Jeanne M. Houston operated the instrument for the calibration program.

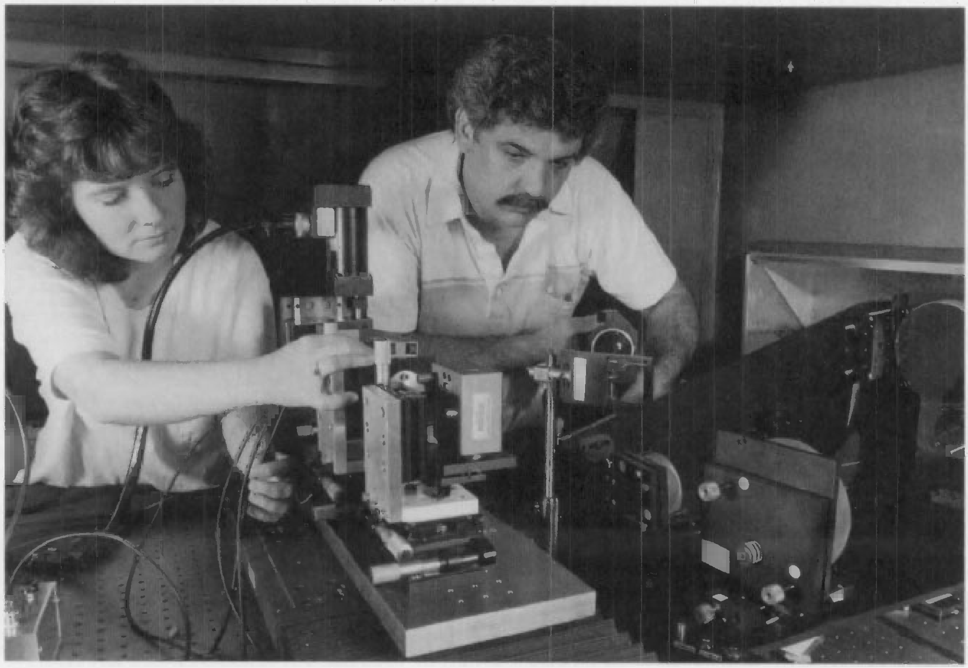
More on Silicon Photodetectors

We described the initial stages of detector-based radiometry in the section entitled *Progress in Optical Radiation Measurements* in Ch. 3. During the tenure of John Lyons, analysis of the response of silicon to radiant energy continued. Jon Geist and Alan Migdall collaborated with Henry Baltes, a guest scientist from the ETH Institute of Quantum Electronics in Zurich, Switzerland, in a detailed study of the silicon absorption coefficient in the spectral range near 760 nm (1.63 eV). They sought to verify or refute evidence obtained in optical density spectra by NIST scientists Richard A. Forman and W. Robert Thurber, working with David E. Aspnes of the Murray Hill, New Jersey, Bell Telephone Laboratories research center, that an indirect transition occurred in silicon at that energy.

For their investigation, Geist, Migdall, and Baltes employed a stabilized ring dye laser to irradiate a 100 μm thick, 2.5 cm diameter wafer of high-purity silicon. The silicon wafer, held at a 45° angle to the laser beam, was backed by a calibrated silicon photodiode, so that accurate measurements could be obtained of its absorption coefficient. They found a smooth absorption spectrum in the range 1.61 eV to 1.65 eV, with no features as large as a few parts in 1000 that would support the existence of a transition at 1.63 eV.

In a study intended to provide the best available accuracy for the silicon absorption coefficient at 633 nm, Geist, Jun-Feng Song, Yun Hsia Wang, and Edward F. Zalewski of NIST, in collaboration with A. Russell Schaefer, a former NIST colleague then at Science Applications International Corporation of San Diego, derived a value of $(3105 \pm 62)\ \mathrm{cm}^{-1}$. Their value was lower by about 15 % than handbook values but they believed it to be more accurate by virtue of improved sample quality and more reliable thickness and transmittance measurements.[152]

[152] Jon Geist, Alan Migdall, and Henry Baltes, "Shape of the silicon absorption coefficient spectrum near 1.63 eV," *Applied Optics* **29**, No. 24, 3548-3554 (1990). See also Jon Geist, A. Russell Schaefer, Jun-Feng Song, Yun Hsia Wang, and Edward F. Zalewski, "An accurate value for the absorption coefficient of silicon at 633 nm," *J. Res. NIST* **95**, No. 5, 549-558 (1990).



On the automated spectral comparator facility, physicists Jeanne M. Houston and Chris L. Cromer aligned the silicon photodiode light traps that were used in photodetector research and calibration.

Low Background Infrared Calibration Facility

The Bureau's Low Background Infrared Calibration Facility (LBIR), discarded in 1985 because of old age and high maintenance costs, was reborn in 1991 at the hands of Raju Datla, Steven Lorentz, and Stephen C. Ebner. Datla designed an infrared monochromator for the spectral calibration of infrared sources—principally blackbody devices, detectors, and optical components. Lorentz developed a laser-based infrared source to provide radiation in the range 2 μm to 25 μm. Ebner was responsible for development of a low background blackbody source.

The Department of Defense contributed funds for the resurrection because of the national need for the calibration capability.

Datla, Ebner, James Proctor, and Albert C. Parr described the new LBIR facility in *NIST Handbook 147*.[153] The facility was placed within a class 10,000 cleanroom 4.3 m by 5.2 m by 3.2 m high, with storage and assembly space outside. A closed-cycle helium refrigerator, built by Donald McDonald and Joseph Sauvageau of the Boulder Electromagnetic Technology Division, provided cooling to 2 K for the instrumentation.

[153] R. U. Datla, S. C. Ebner, J. Proctor, and A. C. Parr, "LBIR Facility User Handbook," *NIST Handbook 147*, June 1991, 23 pp.

A vacuum tank capable of reaching pressures as low as 10^{-7} Pa housed the radiation source to be calibrated, as well as the detector. The standard detector was an absolute cryogenic radiometer (ACR) of the type described earlier in this section. It absorbed more than 99.5 % of all incoming radiation in the spectral range 0.3 μm to 30 μm, providing an overall uncertainty of 1 %. Electrical substitution radiometry was used for the measurement of radiative flux. The ACR could be placed in any of three positions along the optic axis of the system to accommodate sources with different radiant fluxes.

Data collection was performed with a menu-driven computer program that incorporated data files, data reduction, and plotting routines.

Cleanliness, both within the cleanroom and within the vacuum tank, were considered vital. Hydrocarbon contamination of the vacuum tank was especially minimized to preserve the quality of the LBIR optics. Instructions were presented to guide the user in pieparing for clean and accurate calibrations.

Quantum Metrology, Richard D. Deslattes, chief

Lattice Period of Silicon

Richard D. Deslattes and Ernest G. Kessler, Jr. described for the *1990 Conference on Precision Electromagnetic Measurements* the current status of measurements of the lattice spacing in silicon. The discussion necessarily included an update on the division's recently modified x-ray/optical interferometry experiment (XROI).[154]

The XROI experiment, contained in an ion-pumped, thermostated vacuum chamber, was protected from most mechanical vibration by an air spring, a granite support, and an acoustically damped enclosure.[155] Recent additions to the experimental setup included two new laser systems and a revised computer automation capability. One of the lasers, a variable-frequency local oscillator, was monitored continuously by an iodine-stabilized He-Ne laser used as the system reference. The other laser had a fixed frequency; it was used to monitor the trajectory of measurement components.

Measurements of the silicon lattice distance involved excursions of about 280 optical orders, traversed back and forth over periods of 10 h to 20 h. At each measurement point, the x-ray phase was determined by x-ray intensity measurements. The effect on the x-ray phase of pitch and yaw errors was estimated as trajectory curvature.

The primary output data of the XROI-silicon experiment was the rate of change of the x-ray phase with respect to distance covered within the crystal. Uncertainty in the silicon lattice spacing remained at a level of about 0.3 ppm, despite the XROI intrinsic capability for more accurate measurement. With the use of a double-crystal Laue x-ray spectrometer, stated the authors, lattice parameters of silicon crystals could be compared with an uncertainty less than a tenth as large.

[154] Richard D. Deslattes and Ernest G. Kessler, Jr., "Status of a silicon lattice measurement and dissemination exercise," *IEEE Transactions on Instrumentation and Measurement* **40**, No. 2, 92-97 (1991).

[155] The authors noted, however, that noises from nearby traffic and wind outside the building were easily detectable.

Polarized X-Ray Emission Spectroscopy

Capitalizing on earlier studies using synchrotron radiation to excite polarized x rays from molecules in the gas phase, Dennis W. Lindle, Paul L. Cowan, Terrence Jach, Robert E. LaVilla, Richard D. Deslattes, and their colleague R. C. C. Perera of the Lawrence Berkeley Laboratory undertook a detailed investigation of four chlorinated methane compounds—CH_3Cl, CF_3Cl, CF_2Cl_2, and $CFCl_3$.[156]

The group found that they could observe highly polarized molecular valence x-ray fluorescence from each of the test gases. Their experiments made use of x rays from the NIST synchrotron light source that were energy-selected by a large-aperture double-crystal monochromator, providing a well-resolved, intense excitation beam. Ionization chambers monitored both incident and transmitted flux, allowing the team to determine relative photoabsorption cross sections as a function of photon energy for each sample. A Johann-geometry secondary spectrometer analyzed the x-ray emission; use of a silicon crystal in connection with the secondary spectrometer provided polarization analysis of the emitted radiation.

A wealth of information on the x-ray emission properties of the test molecules came from the experiments, leading the researchers to observe that the degree and the direction of x-ray polarization in the chlorinated methanes was sensitive to the initial excitation energy in the core level region, and sensitive as well to the symmetry properties of the valence molecular orbitals involved in the x-ray emission process.

Shortly after completing the experiments described above, Lindle and Cowan, collaborating with Stephen H. Southworth and R. Mayer, found a strong anisotropy in the polarized chlorine K-V x rays emitted following resonant excitation of CF_3Cl gas with a linearly polarized x-ray beam. It was the first such observation.[157]

Previously it had been supposed that observation of anisotropic x-ray emission from molecular crystals and other solids arose from ordering inherent to the crystalline lattice structures; gas-phase samples were expected to exhibit isotropic x-ray emission. But not so, said the authors—excitation by an incident beam could leave an atom or a molecule in an anisotropic state, which then could influence subsequent photon emission.

The authors accomplished their feat in a fashion similar to the experiment described previously. Linearly polarized x rays from the NIST synchrotron light source were used to excite CF_3Cl molecules to energies near the Cl K edge, and the Cl K-V fluorescence emitted normal to the incident beam was analyzed using a curved-crystal spectrometer. The entire Cl K-V spectrum was analyzed at once by a position-sensitive

[156] D. W. Lindle, P. L. Cowan, T. Jach, R. E. LaVilla, R. D. Deslattes, and R. C. C. Perera, "Polarized x-ray emission studies of methyl chloride and the chlorofluoromethanes," *Phys. Rev.* **A43**, No. 5, 2353-2366 (1991).

[157] S. H. Southworth, D. W. Lindle, R. Mayer, and P. L. Cowan, "Anisotropy of polarized x-ray emission from molecules," *Phys. Rev. Lett.* **67**, No. 9, 1098-1101 (1991).

proportional counter. Angular distribution of the x-ray emission was made possible by rotating the target chamber and the emission spectrometer. Variation in the energy of the exciting beam produced different patterns, interpreted by the researchers as representing the properties of different quantum levels of the target molecule. The authors were able to describe their results in terms of a classical model of the x-ray absorption-emission process.

Ionizing Radiation, Randall S. Caswell, chief

Radon, Invader of Homes

During the 1970s, environmentalists throughout the world became aware that radon gas, mainly in the form of ^{222}Rn, was seeping from the earth into certain dwellings, exposing the occupants to a low-level hazard from radioactivity. NBS quickly developed two approaches to ameliorate the radon problem. One provided a device to evaluate the natural rate of exchange of air between the inside and outside of homes. Owners of homes with rapid air exchange had little reason to fear a buildup of radon within their homes.

The other program involved detection of radon and the creation of standards of measurement for its concentration within homes. The radioisotope ^{222}Rn is a decay product of radioactive ^{226}Ra. The 4 day half-life of ^{222}Rn is short compared to the 1600 year half-life of its radium parent, which occurs naturally in many areas. The ubiquity and striking variability in concentration of radon gas was described simply by Klement:

> Radon is released as a decay product [of ^{226}Ra] from soils, rocks, waters, and building materials. It is also contained in natural gas and other fossil fuels. Radon concentrations vary considerably from place to place and from time to time. [158]

The enormous variability in concentration of terrestrial radon gas, plus the fact that its decay half-life was only 4 days, made it a challenging problem for standards scientists. In June 1989, a 1 day seminar in Braunschweig, Germany, brought together an international group of scientists who shared information about efforts in their own countries to perfect calibration schemes for use in radon detection programs operated by state and local governments. According to J. M. Robin Hutchinson, the favored methods for detection and quantification of radon gas involved ionization-chamber or scintillation-cell measurements of alpha particles emitted by ^{222}Rn samples, and gamma-ray measurements of radon decay products.[159]

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[158] Alfred W. Klement, Jr., "Natural sources of environmental radiation," section in *CRC Handbook of Environmental Radiation* (Boca Raton, Florida: CRC Press, Inc. 1982), Alfred W. Klement, Jr., editor, pp. 5-22.

[159] J. M. R. Hutchinson, "Radon measurement standards and calibration," Preface to issue No. 2, *J. Res. NIST* **95**, (1990).

The NIST calibration system was described by R. Collé, Hutchinson, and M. P. Unterweger. The system used as its reference ^{226}Ra sources three Standard Reference Materials consisting of radium solutions of different concentrations. The radon gas generated by the decay of the radium atoms in solution was separated from the solution in a gas-handling system, then the alpha particles resulting from the decay of the radon atoms were detected in pulse ionization chambers. NIST used the ionization chambers preferentially because of their stability.[160]

Perfecting a Radioactive Standard

Because ^{186}Re was under consideration in the 1990s as a therapeutic radioactive isotope, it was important to understand its half-life and its types and levels of radioactive decay. Bert M. Coursey, Jeffrey Cessna, Dale D. Hoppes, Frank J. Schima, and Michael P. Unterweger, along with their colleagues E. Garcia-Torano, A. Grau Malonda, J. M. Los Arcos, and M. T. Martin-Casallo of the Center for the Investigation of Energy and Technology of Madrid, Spain, and D. B. Golas and D. H. Gray of the U.S. Council for Energy Awareness in Washington, DC, undertook this task.[161]

Much was already known about the ^{186}Re decay scheme. The isotope decayed with a half-life of about 89 hours by electron capture to ^{186}W and by beta-emission to ^{186}Os. Radiation associated with the decay included a 1 MeV beta particle, a 940 keV beta particle, and gamma rays of 123 keV and 137 keV.

Using ^{186}Re samples obtained commercially in the form of dilute solutions of sodium perrhenate in saline solution, the group employed a method of $4\pi\beta$ liquid-scintillation efficiency tracing—developed jointly by their two institutions—to standardize the activity of the radionuclide. The team then made use of standard solutions to prepare calibration sources for semiconductor spectrometer measurements of the x-ray and gamma-ray probabilities per decay. They also determined the ^{186}Re half-life and obtained calibration factors for the NIST primary ionization chamber.

Taking account of detectable radioactive impurities in their samples, the group obtained a value for the ^{186}Re half-life of 89.25 ± 0.07 h.

Estimating Absorbed Dose in Food Processing

An important feature of the use of ionizing radiation for the sterilization of foods was the accurate determination of the amount of radiation absorbed during the sterilization process. A multinational group including Marc F. Desrosiers of NIST, G. L. Wilson and D. R. Hutton of the Department of Physics at Monash University in Victoria, Australia, and C. R. Hunter of the Monash Department of Anatomy offered an evaluation method based on electron paramagnetic resonance measurements of irradiated food samples.

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[160] R. Collé, J. M. R. Hutchinson, and M. P. Unterweger, "The NIST primary radon-222 measurement system," *J.Res. NIST* **95**, 155-165 (1990).

[161] B. M. Coursey, J. Cessna, E. Garcia-Torano, D. B. Golas, A. Grau Malonda, D. H. Gray, D. D. Hoppes, J. M. Los Arcos, M. T. Martin-Casallo, F. J. Schima, and M. P. Unterweger, "The standardization and decay scheme of rhenium-186," *Applied Radiation and Isotopes* **42**, No. 9, 865-869 (1991).

Effects from the irradiation of foods were known to show up later in certain analyses by electron paramagnetic resonance (EPR) of bone samples. By re-irradiating samples, one could generate curves of EPR signal amplitude *vs* radiation dosage; extrapolating such curves back to zero signal amplitude then provided an estimate of the initial dose. The EPR signals persisted much longer than the shelf life of the irradiated foods, thus potentially providing a suitable standardized method for evaluating initial doses in the radiation-processing method.

The group focused their efforts on mathematical methods for best analyzing the EPR signal strength-dosage data to provide the most accurate estimates of initial dose. They irradiated samples prepared from ground chicken bones with various measured doses from a ^{137}Cs gamma-ray source. The first irradiation in each case was assumed to be the "initial" dose; subsequent irradiation doses were analyzed to derive experimental estimates of the initial dose.

For initial doses at levels 0.5 kGy and 1.76 kGy, a simple linear plot of dose vs signal amplitude provided acceptable estimates of the initial dose. However, initial doses as high as the legal maximum for chicken processing—8 kGy in certain countries—were estimated less well by the linear approach. Possible complicating features of the method, particularly an unexpected variation in the stablility of the EPR signal amplitude with time after irradiation and a dosage dependence different from linear, were contemplated by the group. In a follow-up article, Desrosiers utilized a response function in which the EPR signal intensity varied with the dose in an exponential manner. This step provided more accurate estimates of initial radiation dosages.[162]

Radiation Transport Theory and Martin J. Berger

During April 1990, a *Symposium on the Physics of Electron Transport* was held at NIST/Gaithersburg in honor of Martin J. Berger, a major contributor to the field during his 36 years at NBS/NIST that ended with his retirement in 1988. The symposium was attended by more than 60 colleagues from North America and Europe. Three sessions held over the 2 days of the symposium featured 8 papers on various aspects of the topic, including five presented by Berger and by four of his long-term co-workers Ugo Fano, Lewis V. Spencer, Stephen M. Seltzer, and Mitio Inokuti.[163]

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[162] M. F. Desrosiers, G. L. Wilson, C. R. Hunter, and D. R. Hutton, "Estimation of the absorbed dose in radiation-processed food—1. Test of the EPR response function by a linear regression analysis," *Appl. Radiation and Isotopes* **42**, No. 7, 613-616 (1991). See also M. F. Desrosiers, "Estimation of the absorbed dose in radiation-processed food—2. Test of the EPR response function by an exponential fitting analysis," *Appl. Radiation and Isotopes* **42**, No. 7, 617-619 (1991).

[163] Martin J. Berger, "Differences in the multiple scattering of positrons and electrons," *Appl. Radiation and Isotopes* **42**, No. 10, pp. 905-916 (1991); Stephen M. Seltzer, "Electron-photon Monte Carlo calculations: the ETRAN code," ibid., pp. 917-942; Lewis V. Spencer, "Notes on electron penetration," *ibid.*, pp. 943-952; U. Fano and Ning-Yi Du, "Dissipative polarization by slow electrons," *ibid.*, pp. 975-978; and Mitio Inokuti, "Subexcitation electrons: an appraisal of our understanding," *ibid.*, pp. 979-984.

In a synopsis of Berger's career, Randall S. Caswell and Robert Loevinger noted that Berger had developed a unique approach to photon transport based upon the use of Monte Carlo calculations. Identified by the acronym ETRAN, a computer program telescoped the multitudinous collisions between ionizing particles and complex media into a manageable series of random-walk segments characterized by energy loss and directional changes. The program, initially developed in the 1960s, was, they said, still the most accurate available for transport calculations.

Time and Frequency, Donald B. Sullivan, chief

Rydberg Constant

One of NIST's contributions to the science of fundamental physical constants that has not been discussed elsewhere in this volume came from Howard P. Layer, James C. Bergquist, and their colleagues Ping Zhao, W. Lichten, and Zhi-Xiang Zhou from Yale University.[164] They performed a new determination of the Rydberg constant, providing the value (109 737.315 73 ± 0.000 03) cm^{-1}. At the heart of their determinations was the wavelength and frequency reference embodied in a $^{127}I_2$-stabilized helium-neon laser.

The experiment accomplished by Layer, Bergquist and their colleagues involved measurement of the 2S-4P Balmer-β line in hydrogen and deuterium. A cw dye laser beam was used to quench the metastable atomic beam through the transition, with the iodine-stabilized laser serving as the frequency and wavelength standard. The experiment yielded four independent measurements of the Rydberg constant (in cm^{-1}): 109 737.315 770; 109 737.315 720; 109 737.315 692; and 109 737.315 741. The four values differed from the average, 109 737.315 731 cm^{-1}, by no more than 4 parts in 10^{10}.

Essays on Time and Frequency

The Institute of Electrical and Electronics Engineers devoted the July 1991 issue of its proceedings to papers on time and frequency. The editors of the special issue were James L. Jesperson and D. Wayne Hanson, veteran staff members of NIST's Time and Frequency division. Among the scientists invited to review progress in various aspects of the subject, we take note of these:

- Norman F. Ramsey, emeritus professor of physics at Harvard University, who received the 1989 Nobel Prize in physics for work basic to the development of atomic time and frequency standards ("The past, present, and future of atomic time and frequency").
- Donald B. Sullivan and Judah Levine of NIST's Time and Frequency division ("Time generation and distribution").
- Wayne M. Itano, also with the NIST Time and Frequency division ("Atomic ion frequency standards").

[164] Ping Zhao, W. Lichten, Zhi-Xiang Zhou, H. P. Layer, and J. C. Bergquist, "Rydberg constant and fundamental atomic physics," *Phys. Rev.* **A39**, No. 6, pp. 2888-2898 (1989).

- Steven L. Rolston and William D. Phillips of NIST's Atomic Physics division ("Laser-cooled neutral atom frequency standards").[165]
- Jacques Rutman, Deputy Director of the French Committee of the International Union of Radio Science (URSI), and Fred L. Walls, a senior staff member of the Time and Frequency division ("Characterization of frequency stability in precision frequency sources").

We briefly outline 3 of these contributions in the next sections.

Stability of Precise Frequency Sources

Publication of the special issue mentioned above provided a fine opportunity for Fred L. Walls and Jacques Rutman to review progress in high-precision frequency standards over the past three decades. Their discussion focused on the question of stability of frequency sources.

The authors noted the advent of the cesium beam atomic clock in 1955, which led to the commercial manufacture of such time-keepers—cesium beams and optically pumped rubidium clocks—by the thousands. Progress in the quality of oscillators controlled by quartz crystals made them useful, too, in such applications as fundamental metrology, telecommunications, space projects, and commercial broadcasting.

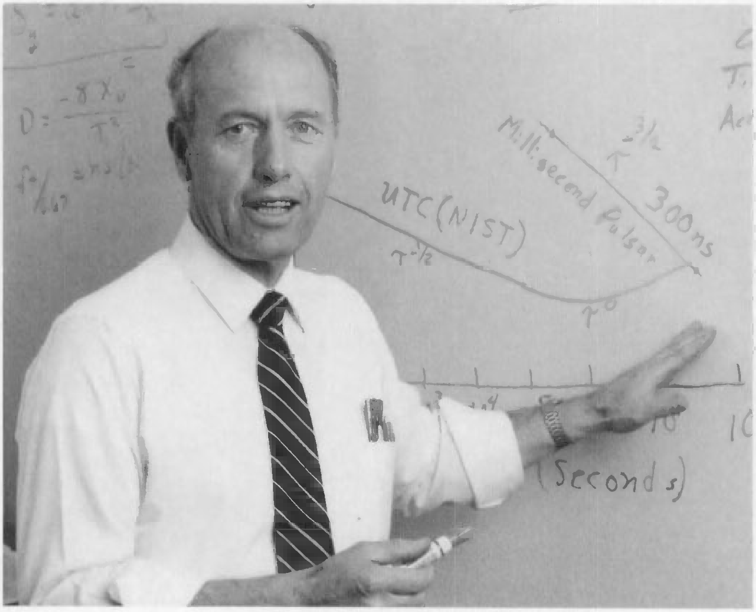
In the early 1960s, the stability of the frequency underlying the chronometric devices was addressed to facilitate comparisons among laboratories and among devices, and to assess the relation between frequency stability and satisfactory performance in specialized applications.

Rutman and Walls pointed out that frequency stability of real oscillators could be characterized only after considering the nature of such devices. For example, their (theoretically) perfect sine-wave outputs were perturbed by random noise or drifts caused by aging or environment. Solution of this problem required development of mathematical models that could account for such deviations from sinusoidal output signals. These models allowed the introduction of tools useful for the characterization of fluctuations—correlation functions, spectral densities, averages, and standard deviations. Quickly, two types of analysis developed: spectral descriptions of phase- and frequency fluctuations in the Fourier frequency domain, and averages of fluctuations in the time domain. NIST's David W. Allan was a pioneer in the use of variances in the study of frequency stability.

The authors brought up to date the progress of stability studies rooted in the concepts they had outlined. They noted, however, that in 1991 there was no single analytical mode that would produce a "best" measure of frequency stability.[166]

[165] This work is discussed in *Sharper Lines from Cooler Atoms* in Ch. 4. Phillips shared the 1998 Nobel Prize in physics for his work on laser cooling.

[166] Jacques Rutman and F. L. Walls, "Characterization of frequency stability in precision frequency sources," *Proc. IEEE* **79**, No. 7, pp. 952-960 (1991).



David W. Allan explained the methods used to measure performance of different clocks and to transfer time worldwide.

Frequency Standards Based on Trapped Ions

Wayne M. Itano described for the special time and frequency issue the progress to date on frequency standards based on the use of trapped ions, a topic discussed elsewhere in this volume. The basic premise in such devices was that the frequency of an oscillator could be locked to a resonance corresponding to a transition between two energy levels of an atomic ion, held in space by a combination of electric and magnetic fields.

A microwave frequency standard that was already a reality in 1991 utilized $^{199}Hg^+$. Others under development involved $^{9}Be^+$, $^{137}Ba^+$, or $^{171}Yb^+$. Some studies were then in progress at NIST on the use of narrow-linewidth transitions in single trapped ions for optical frequency standards.

Itano briefly described the Penning trap, which utilized static electric and magnetic fields to hold the ions near the center of the trap, and the Paul trap, involving a radiofrequency potential applied to electrodes of particular geometries. He noted that the accuracy of the frequency derived from trapped ions depended upon phenomena that could shift the resonance frequency of the ions—such factors as collisions with background gas, perturbations caused by external fields, and Doppler shifts. Cooling of the ions provided a useful escape from Doppler effects. Itano called attention to the use of laser cooling for this purpose by himself and David J. Wineland[167] and by Claude Cohen-Tannoudji and William D. Phillips.[168]

Often, Itano pointed out, it was necessary to trade accuracy for stability in trapped-ion frequency standards.

Itano outlined the use of $^{199}Hg^{+}$ in both microwave and radiofrequency standards, he noted NIST work on laser cooling of $^{9}Be^{+}$ ions, and he mentioned other frequency standards based on the probing of a single ion.[169]

Technology of Frequency and Time

Donald B. Sullivan and Judah Levine discussed at length for the IEEE Proceedings the generation and distribution of frequency and time signals using the latest available methods.[170] The two scientists opined that laser manipulation of atoms and satellite time transfer already provided the potential for accuracy that would be superior to existing atomic frequency standards. They pointed out that the stability of a frequency standard was a measure of its ability to remain within specific limits for a given time, whereas its accuracy was based on comparisons with a physical model of the standard.

Frequency standards, according to Sullivan and Levine, jumped in accuracy with the earlier developments of quartz-crystal oscillators and atomic clocks. Quartz oscillators constituted the least expensive class of frequency standards. Increasingly superior in performance—but also increasingly expensive—were rubidium standards, cesium-beam standards, and hydrogen masers. A limit on the performance of these atomic standards, however, was the Doppler effect, arising from their operation at room temperatures or even higher temperatures.

Comparisons of clocks benefitted enormously from the use of satellite methods, which allowed uncertainties as low as 10 ns on a global level, better than typical performance characteristics of individual clocks.

So-called "trapped ion" frequency standards, then under development by David J. Wineland, Robert E. Drullinger, and Fred L. Walls in Boulder, and "trapped neutral atoms," then under development by William D. Phillips and his group in Gaithersburg, offered two major advantages over conventional atomic devices—essentially zero first-order Doppler shifts because of the near-immobility of the ions or atoms, and reduction of transition linewidths because of the availability of long observation times.

Sullivan and Levine described current methods of time transfer as falling into one of three categories; one-way, common-view, and two-way. In the one-way case (typified by the broadcast signals from WWV), a time signal from a source to a user was delayed by the medium through which the signal passed; the delay had to be estimated

[167] D. J. Wineland and W. M. Itano, "Laser cooling," *Physics Today* **40**, pp. 34-40, June 1987.

[168] C. N. Cohen-Tannoudji and W. D. Phillips, "New mechanisms for laser cooling," *Physics Today* **43**, pp. 33-40, October 1990.

[169] Wayne M. Itano, "Atomic ion frequency standards," *Proc. IEEE* **79**, No. 7, pp. 936-941 (1991).

[170] Donald B. Sullivan and Judah Levine, "Time generation and distribution," *Proc. IEEE* **79**, No. 7, pp. 906-914 (1991).

Wayne M. Itano adjusted an external frequency doubler, which was part of a laser setup for the mercury ion clock experiment.

in order to synchronize the user's signal. In the common-view case (typified by the use of the Global Positioning Satellite), both the source and the user compared their clocks to a reference visible to both. The difference between the medium-based delays experienced by the source and the user—often much smaller than either time delay considered by itself—had to be estimated to yield the correct relation between source and user clocks. In the two-way case (for example, two-way broadcasting between the source and the user via a satellite), the source and the user would exchange timing data. In favorable instances such an exchange would allow nearly perfect cancellation of the delay error. Sullivan and Levine estimated best-case accuracy at 100 ns and available stability at 10 ns. They saw the evaluation of time-delay error as the outstanding problem facing progress in time transfer.

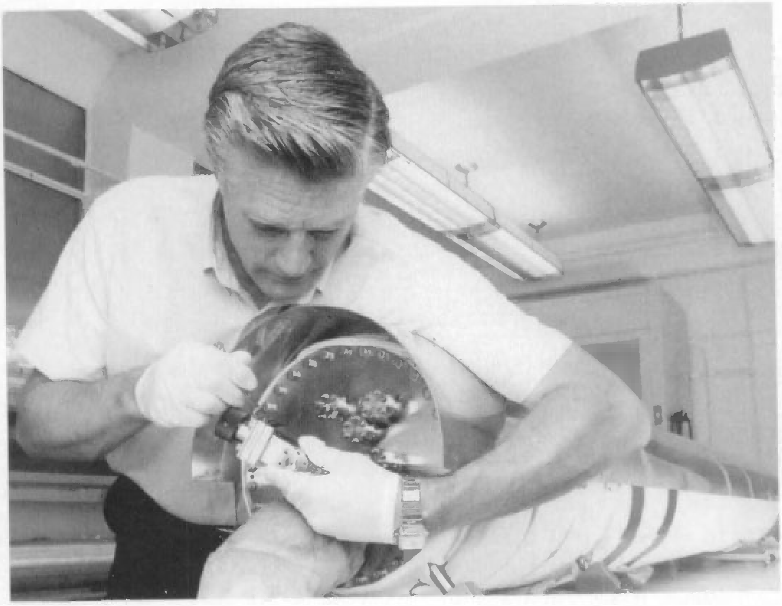
Optically Pumped Cesium Frequency Standard

In 1991, Time and Frequency Division scientists were in the process of developing an optically pumped, cesium-beam primary frequency standard. They were confident that such an instrument would exhibit unusually good stability compared to conventional cesium standards.

The new device was conceived by Robert E. Drullinger, David J. Glaze, John L. Lowe, and Jon H. Shirley. In considering the improvement, they analyzed several systematic uncertainties that afflicted the conventional cesium apparatus: fluorescent light shift; second-order Doppler shift; end-to-end cavity phase shift; Rabi-pulling; cavity-pulling; Majorana effects; RF spectral purity; and magnetic field uniformity.

The new instrument featured a 3 mm diameter atomic beam, derived from a new oven design. The vacuum chamber was 25 cm in diameter and 2.5 m long. Instead of using "off-the-shelf" laser diodes, the authors employed a laser-line-narrowing method based on optical feedback from a high *Q* cavity. They felt that their improvements would yield a line-center accuracy somewhat better than one part in 10^8.

First results were promising, leading the group to predict excellent short-term stability and an overall frequency accuracy of about one part in 10^{14}.[171]



Physicist David J.Glaze adjusted NIST 7, an atomic clock used as an international time standard.

[171] Robert E. Drullinger, David J. Glaze, J. L. Lowe, and Jon H. Shirley, "The NIST optically pumped cesium frequency standard," *IEEE Trans. on Instrum. and Meas.* **40**, No. 2, pp. 162-164 (1991).

Quantum Physics, David W. Norcross, chief

Making New Lasers

Stephen R. Leone, a staff member of both the Quantum Physics division and the Joint Institute of Laboratory Astrophysics, and his JILA colleague Harold C. Miller spent the early 1990s investigating the lasing properties of various systems in an effort to produce lasers for special applications.

With Katsuyoshi Yamasaki of the University of Tokyo and John E. Smedley of Bates College, the two researchers demonstrated that a laser operating between 300 nm and 350 nm could be obtained using the unstable radical sulfur monoxide (SO). Lasing had already been demonstrated in heteronuclear diatomics—NO, IF, and NaK—by pumping energy into the ground state of the molecule and exciting it to a higher level. Such systems, the authors noted, provided excellent opportunities for the study of the influence of the dynamic Stark effect and the stimulated Raman effect on laser processes. In certain cases, the lasers offered high-resolution, Doppler-free spectroscopy as well.

The group knew that the SO radical could be prepared by irradiating sulfur dioxide at 193 nm. They used an argon fluoride excimer laser, irradiating flowing SO_2 for this purpose; it produced SO in the $X^3\Sigma^-$ electronic state. A pumping pulse at 256 nm was obtained by frequency-doubling the visible output of a dye laser. This pulse populated the $B^3\Sigma^-$ state of SO. Emission from the excited SO radicals was observed using monochromator-photomultiplier detection in the 300 nm to 400 nm range. Spontaneous emission appeared in the form of about a dozen lines in that range, and four relatively sharp stimulated emission lines appeared in the range 300 nm to 350 nm.[172]

Miller and Leone also collaborated with Robert L. Pastel of the University of New Mexico and G. D. Hager of Kirtland Air Force Base in Albuquerque to demonstrate lasing at 2.7 μm in atomic bromine. Technical needs for efficient lasers in the mid-infrared spectral range made this work particularly useful.

The authors prepared excited bromine atoms by photolyzing IBr with light at 532 nm. A pump laser—a frequency-doubled neodymium-yttrium-aluminum garnet laser operated at 532 nm—produced laser radiation from the excited bromine atoms with a temporal distribution that varied noticeably with the pump energy. The 2.7 μm laser emission appeared to arise from the $4\,^2P_{1/2}$–$4\,^2P_{3/2}$ transition in atomic bromine. The maximum pump energy conversion efficiency was calculated to be 1.5 %, relatively high for such a process.[173]

[172] Harold C. Miller, Katsuyoshi Yamasaki, John E. Smedley, and Stephen R. Leone, "An optically pumped ultraviolet laser on SO($B_3\Sigma^-$–$X^3\Sigma^-$)," *Chem. Phys. Lett.* **181**, No. 2, 3, pp. 250-254 (1991).

[173] Robert L. Pastel, G. D. Hager, Harold C. Miller, and Stephen R. Leone, "Efficient Br* laser pumped by frequency-doubled Nd:YAG and electronic-to-vibrational transfer-pumped CO_2 and HCN lasers," *Chem. Phys. Lett.* **183**, No. 6, pp. 565-569 (1991).

Electron-Impact Excitation Cross Sections

A new technique for the measurement of cross sections for the excitation of multiply charged ions by electron impact was put forward by a group of scientists at the Joint Institute for Laboratory Astrophysics late in 1990. The group included Gordon H. Dunn, on the staff of JILA and also the NIST Quantum Physics Division; JILA members E. K. Wahlin and J. S. Thompson; R. A. Phaneuf and D. C. Gregory of the Oak Ridge National Laboratory; and A. C. H. Smith of University College in London.

The authors noted the important role played by highly charged ions in studies of fusion, lasers, and astrophysics, as well as the lack of experimental information on electron-impact excitation of such species.

To help close the gap in that area of physics, the authors developed an apparatus in which electrons were merged with ions in an analyzer involving crossed electric and magnetic fields. After colliding with the ions, the electrons were removed from the stream with a second analyzer and detected with a position-sensitive detector. The detection efficiency approached unity—orders of magnitude higher than conventional fluorescence or differential monochromator techniques.

The new method had the additional advantages of providing absolute cross section values, operating near the critical threshold, and providing data on non-radiating states as well as those that radiated.

The group demonstrated their new method on triply ionized silicon. They chose that species particularly because it resembled sodium and thus could be described with confidence in theoretical terms, thus providing as a bonus an experimental comparison with theory.

The cross section for $3s$ to $3p$ excitation of Si^{+++} by electron impact using the new technique was determined at the 90 % confidence level to be 10^{-15} cm^2 ± 20 % at 9 eV electron energy, in good agreement with theoretical predictions.[174]

Spectroscopy from the Hubble Space Telescope

In August 1991, the *Astrophysical Journal Letters* set aside an issue for the first reports of spectroscopy accomplished using the Hubble Space Telescope. The editors dedicated the issue to Lyman Spitzer, known as the "Father of the Hubble Space Telescope." Spitzer, professor of astronomy at Princeton University for some 30 years, had worked towards the deployment of an orbiting astronomical telescope from the end of World War II.

One of the reports in the special issue described the first results obtained with the Goddard High-Resolution Spectrograph (GHRS) as part of the Science Assessment Program for the Hubble Space Telescope. Members of the GHRS team included Jeffrey L. Linsky, a staff member of JILA and NIST; JILA staff scientist Alexander

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[174] E. K. Wahlin, J. S. Thompson, G. H. Dunn, R. A. Phaneuf, D. C. Gregory, and A. C. H. Smith, "Electron-impact excitation of Si^{3+} ($3s$–$3p$) using a merged-beam electron-energy-loss technique," *Phys. Rev. Lett.* **66**, No. 2, pp. 157-160 (1991).

Brown; Kenneth G. Carpenter, Richard D. Robinson, Glenn M. Wahlgren, and Thomas B. Ake, of the NASA/Goddard Space Flight Center; Dennis C. Ebbets of the Bell Aerospace Systems Group; and Frederick M. Walter of the State University of New York at Stony Brook.

The report emphasized the types of observations that could not have been obtained without the new equipment, in this case high-precision spectra from the star α Tauri. The authors wrote:

> This [Hubble project] study of α Tau produced the highest quality ultraviolet spectra ever obtained of a cool star. The high dynamic range of the data allowed detection of 25 new emission lines from α Tau, 10 of which do not appear in the solar spectrum. The accurate wavelength calibration led to a confident measurement of flow velocities for most of the spectral lines, but also indicated the need for more precise laboratory wavelengths for ions such as Co II.[175]

It was clear that orbiting astronomical instruments, disparaged in their early days because of a "birth defect" in the Hubble telescope optics, had before them a very useful career.

Linsky was also part of a group utilizing the Very Large Array (VLA), a radio telescope facility of the National Radio Astronomy Observatory, to survey some 26 main-sequence, giant, and supergiant stars in a search for radio emissions at 2 cm and 6 cm wavelengths. Linsky was joined in the search by P. G. Judge of JILA, S. A. Drake of ST Systems Corporation, and M. Elitzur of the University of Kentucky. Within the limits of the VLA sensitivity, the group obtained no signals from the dwarf stars, indicating that such stars emit weakly, if at all, at radio frequencies. Three of the cool stars—two M giants and an infrared carbon star—were identified as radio sources. On the basis of their measurements, the group estimated the temperature of the infrared carbon star, IRC + 10216, as only about 2000 K. [176]

Materials Science and Engineering Laboratory

In 1984, Lyle H. Schwartz came to NBS as director of the Bureau's Center for Materials Science after 20 years with Northwestern University, including service as director of the N. U. Materials Research Center beginning in 1979. The following year, the center became an institute—like the Institute for Computer Sciences and Technology an entity separate from the National Measurement Laboratory and the National Engineering Laboratory. The Institute for Materials Science and Engineering (IMSE) comprised an Office of Non-Destructive Evaluation and five divisions, devoted to studies in inorganic materials, fracture and deformation, polymers, metallurgy, and reactor radiation.

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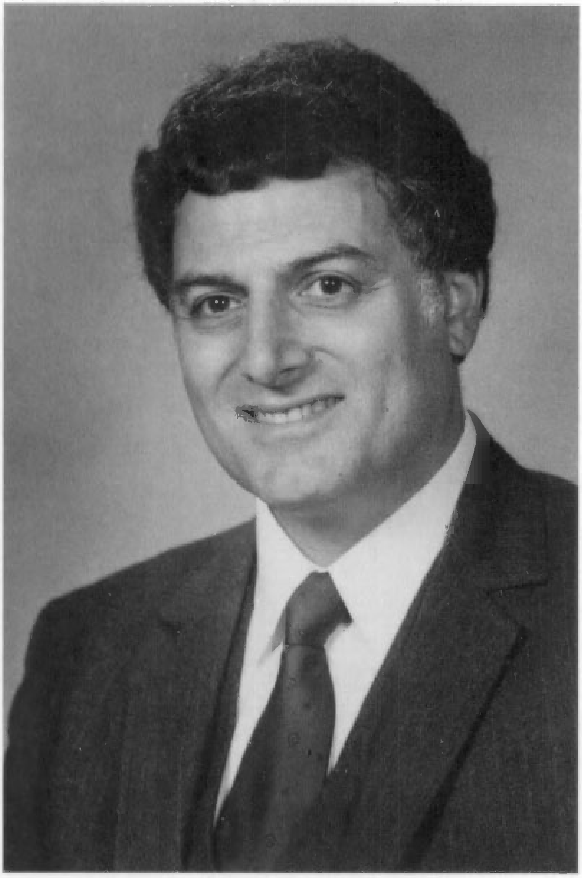
[175] Kenneth G. Carpenter, Richard D. Robinson, Glenn M. Wahlgren, Thomas B. Ake, Dennis C. Ebbets, Jeffrey L. Linsky, Alexander Brown, and Frederick M. Walter, "First results from the Goddard High-Resolution Spectrograph: the chromosphere of α Tauri," *The Astrophys. J.* **377**, L45-L48 (1991).

[176] S. A. Drake, J. L. Linsky, P. G. Judge, and M. Elitzur, "Radio-continuum observations of a variety of cool stars," *The Astronomical Journal* **101**, No. 1, pp. 230-236 (1991).



Lyle H. Schwartz, an expert in the phase transitions in iron alloys, x-ray and neutron diffraction, and catalysis, joined NBS as Director of the Materials Science and Engineering Laboratory in 1984.

As NBS became NIST in 1988, IMSE became the Materials Science and Engineering Laboratory, with the Inorganic Materials and the Fracture and Deformation divisions reconstituted as Ceramics and Materials Reliability, respectively. The Laboratory increased its emphasis on the advanced materials needed for up-to-date manufacturing and construction processes. Research initiatives focused on ceramics, metals, polymers, composites, and superconductors. In mid-1991, the Office of Non-Destructive Evaluation was renamed the Office of Intelligent Processing of Materials.

Office of Intelligent Processing of Materials, H. Thomas Yolken, chief

The OIPM had but three scientists on its staff in 1991; H. Thomas Yolken, John P. Gudas—Yolken's deputy—and George Birnbaum. Theirs was a task in matrix management, to facilitate work in specific technical areas without direct supervisory power over the rsearchers who were involved in the investigations.

The change in name of Yolken's office was indicative of a larger mission—not only to continue to encourage studies of non-destructive testing, but to focus work in technical divisions both within MSEL and elsewhere in NIST on joint materials projects with industrial firms. These latter projects involved the processing of metal powders, modernized steel manufacture, and metallic joining techniques. Companies such as General Electric, United Technology Pratt and Whitney, Crucible Materials Corporation, and Martin Marietta Energy Systems teamed with the Department of Energy and NIST scientists to create the projects.

Ceramics, Stephen M. Hsu, chief; succeeded by Stephen W. Freiman, 1991

Research in ceramics in the 1990s covered a range of topics—processing methods, including the effect of sintering on particle size and shape; surface properties as related to wear and machinability; electro-optic crystals; mechanical properties; phase equilibria; and measurement techniques. A few examples from the work of this division follow.

Standards and Data

In 1991, three new Standard Reference Materials—SRM 1414, a lead-silica glass resistivity reference; SRM 8501, a lubrication oil-oxidation catalyst; and SRM 710a, a soda-lime-silica glass reference—joined more than 70 other standard materials developed and produced by division scientists.

Other standards accomplishments during this period included:

- Development of 25 analytical procedures for the evaluation of the properties of ceramic powders.[177]
- Adoption by the American Society for Testing and Materials of two tests for mechanical properties of ceramics developed by a group led by George D. Quinn.[178]
- Completion of a 350-entry database on material and tribological properties of advanced ceramic materials, by Ronald G. Munro and Edwin F. Begley. Properties data evaluated by Munro and Begley included thermodynamic transport properties, heat capacity, bulk and shear moduli, hardness, fracture strength, and creep properties.[179]

[177] See, for example, S. G. Malghan, "Silicon nitride powders and their processing," pp. 562-576 in *Advanced Materials Processing*, P. Ganguli, editor (Amsterdam: Elsevier Science Publishers B. V., 1991).

[178] G. D. Quinn, et al., "Flexural Strength of Advanced Ceramics at Ambient Temperatures," ASTM Standard C-1161, December 1990.

[179] E. F. Begley and R. G. Munro, "The structural ceramics database," *NISTIR 4601*, 1991.

- Completion of three volumes as part of a joint NIST-American Ceramic Society phase-diagram project involving Helen M. Ondik, Stephen W. Freiman, Mary A. Clevinger, Thomas R. Green, Kimberly M. Kessell, Nils Swanson, and Carla G. Messina. The texts produced were: volume 9 in the series "Phase Diagrams for Ceramists"; a 1991 annual report; and a monograph containing nearly 200 phase diagrams pertaining to high-temperature superconductivity.

Characterization of Ceramic Powders

Robert D. Shull, Joseph J. Ritter, and Lydon J. Swartzendruber were interested in the possibilities of preparing magnetic composites with made-to-order properties. Gelled composites of iron and silica, prepared with iron-containing particles of about 2 nm diameter, had been found to be paramagnetic at room temperatures but likely to exhibit ferromagnetism after certain types of processing. The investigation by the three scientists focused on nanocomposites of silica gel with various concentrations of iron in the range 11 % to 40 %. They determined the iron particle sizes by the use of Mössbauer spectra. After gelling and curing the composites, they heated them in hyrdrogen to reduce the iron, then separated them into two samples for further treatment. One set of samples was re-heated in hydrogen to 770 °C, then annealed for an hour in an ammonia atmosphere at 475 °C. The other set was annealed in ammonia at 375 °C for a day. Mössbauer analysis of the first set of samples showed a marked change in the iron component to a form containing iron silicate with a small admixture of α Fe. Weak ferromagnetism at room temperature strengthened continuously on cooling to 10 K, with no apparent phase change. Evidently the short ammonia anneal had no effect on these samples.

The second set of samples exhibited superparamagnetism and an indication of magnetic spin-glass behavior. The magnetic moment per iron atom was enhanced by factors of three to four by the lengthy, medium-temperature ammonia annealing.[180]

Facilitating Crack Detection With Electron Microscopy

Understanding the mechanics of cracks in ceramics required the observation of the crack area during the initiation of stress on samples. To facilitate the use of the scanning electron microscope (SEM) in crack investigations, Brian R. Lawn and James F. Kelly, in collaboration with their colleague Jürgen Rödel of Lehigh University, designed and built a new testing device.

Designed for use with disks about 10 cm in diameter, the device incorporated a piezoelectric force actuator connected by pivot arms to either side of the test disk, which was notched in the crack-test area. The entire device was housed in the sample chamber of an SEM. Actuating voltage to the piezoelectric stressor could be pre-programmed or externally controlled. The SEM in use allowed videotaping of the entire test procedure.

[180] R. D. Shull, J. J. Ritter, and L. J. Swartzendruber, "Change in magnetic state of Fe + silica gel nanocomposites due to low temperature treatment in ammonia," *J. Appl. Phys.* **69**, No. 8, 5144-5146 (1991).

The researchers used alumina and soda-lime glass test disks to illustrate the capability of the new device. "Starter" cracks were initiated in the disks using standard procedures. They found that crack extension generally occurred in a discontinuous fashion between grains. Active grain bridges appeared at intervals over the entire length of the cracks; these were easily seen in illustrations provided in the report. The authors analyzed the crack growth quantitatively to evaluate the toughness of the specimens used in the tests.[181]

Machining Ceramics

The cost of machining ceramic materials in the 1990s occasionally accounted for 90 % of the total cost of highly precise components, in part because of inadvertent damage during the machining process. Said Jahanmir, Lewis K. Ives, Arthur W. Ruff, and Marshall B. Peterson set about to study the state of ceramic machining in America and, if possible, to identify research areas which could lead to significant improvements. Their efforts, recorded in a NIST Special Publication, included literature searches, visits to industrial firms involved in machining ceramics, and the products of a NIST workshop on the topic held in September 1990.[182]

What did they find? First of all, they found that, indeed, the cost of machining was the primary impediment to the introduction of advanced ceramic parts into industrial goods—more so than the admittedly high costs associated with raw materials, processing, and quality control. They also found a serious gap in the store of data on machining methods for ceramics, a fault that tended to keep machining costs high. They identified rapid machining of advanced ceramics as unknown territory that needed careful investigation, along with techniques for the assessment of damage to ceramic components in machining and for automated machining.

The authors recommended a broad program of research to address the roadblocks slowing the adoption of advanced ceramic materials as routine industrial tools:

- Optimization of the grinding process.
- Chemically assisted machining.
- Grinding wheels for machining of ceramics.
- Direct damage assessment methods.
- Non-destructive methods for machining damage evaluation.
- Sensors for real-time surface finish and damage detection.
- Standard Reference Materials for use in tool calibration and evaluating machined parts.
- Post-machining damage remediation.
- Development of high-strength, machinable ceramics.
- Automated systems for high-volume production.

[181] Jürgen Rödel, James F. Kelly, and Brian R. Lawn, "In situ measurements of bridged crack interfaces in the scanning electron microscope," *J. Am. Ceram. Soc.* **73**, No. 11, 3313-3318 (1990).

[182] S. Jahanmir, L. K. Ives, A. W. Ruff, and M. B. Peterson, "Ceramic machining: Assessment of current practice and research needs in the United States," *NIST Special Publication 834*, June 1992, 102 pp.

Properties of Alumina

A group including Gabrielle G. Long, Susan Krueger, R. A. Gerhardt, and R. A. Page used the Small Angle Neutron Scattering facility at the NIST reactor to examine the evolution of pore microstructure in glassy silica and polycrystalline alumina as a function of sintering. They showed that the two major sintering mechanisms, viscous flow and diffusion, led to similar surface-porosity levels.[183] Their work led to improved models for ceramics processing and better predictability for the microstructure of ceramics.

Another group, including Steven J. Bennison, J. Rödel, S. Lathabai, P. Chantikul, and Brian R. Lawn, also investigated the properties of alumina. Focusing on the toughness of the ceramic, which they assumed derived from the interlocking of grains to stop the progression of cracks, they developed a formalism to describe the origins of ceramic toughness. Many features were considered—the strength of internal boundaries, internal stress levels, and other details of alumina microstructure. Scanning electron microscopy observations provided information on many degradation mechanisms, leading to the conclusion that alumina ceramics could be processed to order for various properties.[184]

Creep in Ceramics

Sheldon M. Wiederhorn, D. F. Carroll, and D. Ellis Roberts developed an experimental technique for evaluating the phenomenon of creep in ceramics. The method utilized laser extensometry to follow the displacement of markers attached to the test sections of the samples, which were shaped like dog bones. The tensile fixture featured hot grips and could be used to temperatures as high as 1500 °C.[185]

Materials Reliability, Harry I. McHenry, chief

The Materials Reliability Division was located in the NIST/Boulder laboratories. Its major focus was placed on advanced materials. Division staff developed measurement techniques for process control, for nondestructive evaluation, and for reliability assessment. Long experience in topics such as cryogenics made the scientists aware of the importance of carefully preparing materials for potentially hostile environments in particular applications.

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[183] G. G. Long, S. Krueger, R. A. Gerhardt, and R. A. Page, "Small Angle Neutron Scattering characterization of processing/microstructure relationships in the sintering of crystalline and glassy ceramics," *J. Materials Res.* **6**, No. 12, 2706-2715 (1991).

[184] S. J. Bennison, J. Rödel, S. Lathabai, P. Chantikul, and B. R. Lawn, "Microstructure, toughness curves and mechanical properties of alumina ceramics," *Toughening Mechanisms in Quasi-Brittle Materials*, pp. 209-233, 1991.

[185] D. F. Carroll, S. M. Wiederhorn, and D. E. Roberts, "Technique for tensile creep testing of ceramics," *J. Amer. Ceram. Soc.* **72**, No. 9, 1610-1614 (1989).

Diagnostics With Ultrasound

An MSEL group that included Raymond E. Schramm, Alfred V. Clark, Jr., Stephen R. Schaps, Robert C. Reno, Gerald V. Blessing, and Todd J. McGuire employed ultrasound for a variety of diagnostic purposes in materials science. One development, accomplished with the collaboration of Dragan V. Mitraković of the University of Belgrade, Yossef Cohen of the Nuclear Research Center in Israel, and Peter J. Schull of The Johns Hopkins University, was the detection of defects in the wheels of railroad cars. By embedding a device called an electromagnetic-acoustical sensor in the train tracks, the group found that they could identify wheels with unusual stress conditions or unsatisfactory metallurgical texture—both properties likely to lead to failure of the wheel. The device emitted short bursts of horizontal shear waves and detected anomalies in the echoes.[186]

A prototype residual stress measurement system was delivered during 1991 to the American Association of Railroads for evaluation in its testing center.

In collaboration with the Ford Motor Company, with Robert B. Thompson and Y. Li of the Center for Nondestructive Evaluation at Iowa State University, and with D. Matlock of the Colorado School of Mines, the research group also compared ultrasound with older, mechanical methods of testing sheet steel for its texture and formability. They found an ultrasonic measurement technique that accurately predicted the critical properties of the steel, potentially leading to on-line measurements to replace slower, more expensive mechanical testing in the laboratory.[187]

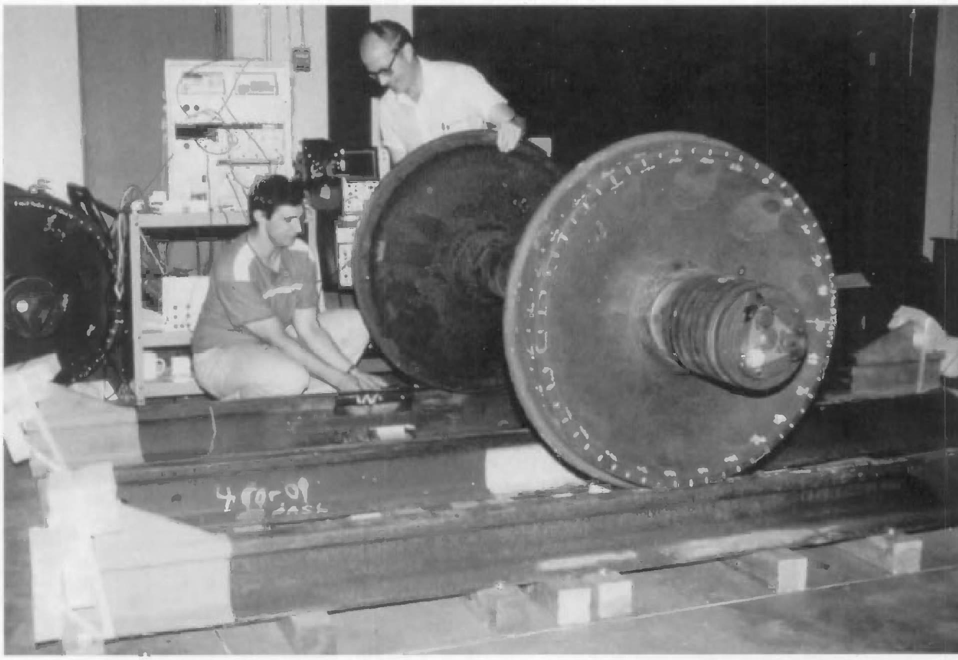
The group also developed electromagnetic probes used in characterizing dielectric materials. A low-frequency capacitance probe could evaluate the density of certain ceramics within 0.2 %.

Nondestructive Testing of Composites

Christopher M. Fortunko, deputy division chief, led a research group dedicated to improving experimental methods for characterization of composites. The group, which included Dale W. Fitting, V. K. Tewary of the Ohio State University, E. Jensen of the Colorado School of Mines, L. J. Bond of the University of Colorado, and M. Renken of Valparaiso University, designed, built, and tested a high-pressure, gas-coupled acoustic microscope capable of 10 μm resolution on silicon wafers. They also produced an acoustic array for the testing of glass-epoxy composites. The gas-coupled microscope operated at frequencies from 10 MHz to 30 MHz and at pressures up to 10 MPa.

[186] Raymond E. Schramm, Alfred V. Clark, Jr., Dragan V. Mitraković, Stephen R. Schaps, and Todd J. McGuire, "Residual stress detection in railroad wheels: an ultrasonic system using EMATs," *NISTIR 3968*, May 1991, 47 pp. See also Raymond E. Schramm, Alfred V. Clark, Jr., Dragan V. Mitraković, Yossef Cohen, Peter J. Schull, and Stephen R. Schaps, "Tread crack detection in railroad wheels: an ultrasonic system using EMATs," *NISTIR 3967*, May 1991, 69 pp.

[187] A. V. Clark, R. B. Thompson, Y. Li, R. C. Reno, G. V. Blessing, D. V. Mitraković, R. E. Schramm, and D. Matlock, "Ultrasonic measurement of sheet steel texture and formability; comparison with neutron diffraction and mechanical measurements," *Res. in Nondestruct. Eval.* **2**, 239-257 (1990).



In 1990, Dragan Mitraković (left), a guest researcher from the University of Belgrade, and NIST physicist Raymond E. Schramm inspected railroad wheels using an Electromagnetic Acoustic Transducer (EMAT) sensor mounted in a typical rail.

A particular challenge for the group was insuring that a composite material was suited to its intended application. This task involved such measurements as quantifying the fiber volume fraction, the fiber orientation, porosity, and quality of bonding between matrix and reinforcing materials in composites. The evaluations were undertaken through the measurement of elastic wave velocities. Absolute phase velocities, for example, could be observed in the determination of elastic moduli.

Cryogenic Properties of Materials

A group led by Harry I. McHenry investigated the behavior of materials at low temperatures. One project, sponsored by the U.S. Air Force Systems Command, provided data on the mechanical properties of aluminum-lithium alloys under consideration for use in the Advanced Launch System (ALS). This was a detailed project. It addressed grain sizes and morphology of samples, hardness, tensile strength, stress-strain relations, and fracture toughness of four different alloy compositions. Richard P. Reed, Patrick T. Purtscher, Nancy J. Simon, Joseph D. McColskey, Robert P. Walsh, John R. Berger, Elizabeth S. Drexler, and Raymond L. Santoyo all contributed to the research.

The materials were envisaged for use in storage of cryogenic fluids. The evaluation project was a textbook case in fitting the material to the application—the reaction of the alloys to stresses caused by a combination of mechanical forces and large temperature excursions had to be predicted. The potential for tank leakage or breakage had to be anticipated, and measurements were needed to guide the choice of optimum composition and configuration of construction materials.

The group found that two prime candidates for the ALS program, Al-Li alloys 2090-T81 and WL049-T851, showed 10 % to 20 % higher tensile yield strength and ultimate strength than the other alloys. Toughness in the alloys, however, proved to depend strongly on the direction of the stress with respect to the orientation of the composites. Many of the measurements addressed fracture toughness and issues relating to delamination of the composites under a variety of stresses. Recommendations were included for further detailed testing of the alloys under actual service conditions.[188]

Oxide Superconductors

Hassel M. Ledbetter and Ming Lei, a colleague from the Institute of Metal Research in Shenyang, China, prepared a comprehensive study of elastic constants and related properties of oxides and oxide superconductors in 1991. Theirs was a contribution to the investigation of high-temperature superconductivity—in part their own measurements and in part the testing of models to provide guidance to others.

The two scientists measured polycrystalline elastic constants by the use of a megahertz-frequency pulse-echo method in the range 4 K to room temperature, employing measured mass density data and a model developed by Ledbetter and S. K. Datta to correct the measurements for voids in the samples. They compared the elastic moduli of $YBa_2Cu_3O_7$ (YBCO) with those of the related perovskites $BaTiO_3$ and $SrTiO_3$ and found good agreement with calculations based on the Born ionic model. They also derived a value of 423 K for the Debye temperature of YBCO, in good agreement with the value obtained from heat capacity data, 440 K.

From these measurements and similar ones on related high-temperature-superconductor materials, Ledbetter and Lei were able to offer conclusions regarding the valence of copper in the compounds and the electron-hole distribution. [189]

Polymers, Leslie E. Smith, chief

Major industrial partners of the Polymers Division included resin producers, processors of polymeric materials, and end-users of polymer-based products. Division scientists assisted these technical partners in understanding the scientific basis for polymer technology, and they helped to provide measurement methods and standards as well.

[188] R. P. Reed, P. T. Purtscher, N. J. Simon, J. D. McColskey, R. P. Walsh, J. R. Berger, E. S. Drexler, and R. L. Santoyo, "Aluminum alloys for ALS cryogenic tanks: comparative measurements of cryogenic mechanicl properties of Al-Li alloys and alloy 2219," *NISTIR 3979,* February 1993, 137 pp.

[189] Ming Lei and Hassel Ledbetter, "Oxides and oxide superconductors: elastic and related properties," *NISTIR 3980,* August 1991, 92 pp., 249 references.

Polymer Vehicles for Printing Inks

An interesting Polymers Division project involved the development of polymeric vehicles for use in various printing processes. In one case, three different types of polymer resins were prepared for trial as potential vehicles for inks to be used in printing by the intaglio technique—in which a plate is engraved or otherwise gouged and inked, and the printing paper is then pressed into the inked depressions. The most successful vehicle, according to Brian Dickens, Barry J. Bauer, and William R. Blair, was found in a family of alkyds based on pentaerythritol, sebacic acid, linseed oil fatty acids, and succinic anhydride. These alkyds formed a group of high-molecular-weight, low-viscosity materials that air-dried well and resisted subsequent wetting with various solvents.[190]

Thermodynamics of Polystyrenes

Questions about the thermodynamics of phase separation in polystyrenes intrigued Robert M. Briber and Barry J. Bauer. They knew that polymeric cross-linking might change the free energy of a given system and lead to phase separation. However, they wanted to study the thermodynamics of single-phase blends of cross-linked and linear polystyrene. Accordingly, they prepared samples containing linear protonated polystyrene and about 1 % of cross-linked deuterated polystyrene. These they analyzed in the small-angle neutron scattering facility at the NIST nuclear reactor.[191]

The two researchers obtained scattering results using an incident neutron beam of wavelength 0.1 nm with a dispersion of 25 %. From these data, they derived static structure factors for the samples as functions of the scattering vectors. They used classical elasticity theory combined with estimates of the free energy of mixing to calculate the zero-angle scattering as a function of the density of the cross links.

Shear Stress and Fluorescence Anisotropy

A new experiment in which measurements of the anisotropy of fluorescence was used to monitor shear-induced molecular orientation in polymer systems was undertaken by Anthony J. Bur, Robert E. Lowry, Steven C. Roth, Charles L. Thomas, and Francis W. Wang early in 1991.

In general, fluorescence anisotropy was expected to depend on the molecular orientation, on the decay time of the fluorescence, and on the rotational relaxation of the probe. The authors provided optical instrumentation for a cone and plate rheometer,

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[190] Brian Dickens, Barry J. Bauer, and William R. Blair, "Cylinder wipe air-drying intaglio ink vehicles for U.S. currency inks," *NISTIR 4498*, January 1991, 23 pp.

[191] Robert M. Briber and Barry J. Bauer, "Small-angle neutron scattering of blends of cross-linked and linear polystyrene," *Macromolecules* **24**, No. 8, 1899-1904 (1991).

and they synthesized a polymeric fluorescent probe molecule consisting of polybutadiene tagged in the center of the principal polymer chain with anthracene. The tagged polybutadiene was expected to participate in the entanglement network of the host matrix of polybutadiene, reflecting the host orientation under applied stress.[192]

The authors observed the anisotropy as a function of shear rate and shear stress for 5 % and 50 % plasticized specimens. They found that the samples displayed non-Newtonian behavior, and they obtained values for the sample relaxation times. They expected the new type of measurement to open windows into the stress-induced behavior of polymers.

Modeling Tooth Decay

Three American Dental Association research associates, using the facilities of the Paffenbarger Research Center at NIST, contributed to the development of mathematical models to describe dental caries. Their study, published in the NIST Journal of Research, expressed the demineralization of teeth in terms of diffusion and dissolution. The three, Thomas M. Gregory, Laurence C. Chow, and Clifton M. Carey, noted the typical progress of decay in teeth: a thin outer layer of enamel in relatively good condition, a deeper layer consisting of partly demineralized enamel, and an advancing front of demineralization where acids diffused into the sound portion of the tooth and dissolved mineral from it.

Other studies had indicated that tooth mineral dissolved faster than the product ions could be transported from the site. Thus, a diffusion-controlled process appeared to be at work. The authors introduced into the modeling process an interaction between the permselective diffusion of ions and the dissolution of tooth mineral. They predicted the existence of concentration gradients in the calcium and phosphate ions, owing to gradients in the electrochemical potentials and differences in the permselectivity of the diffusion barrier. Instead of the concentration ratio 5/3 for Ca/P, as was found in healthy tooth enamel, the loss of these ions to the outer layer of the tooth was limited by the (complex) diffusion process.[193]

Despite the limitations of their assumptions—for example, that the barrier between the decaying portion of the tooth and its outer layer was infinitely thin—the authors found that their results agreed well with available experimental data.

[192] Anthony J. Bur, Robert E. Lowry, Steven C. Roth, Charles L. Thomas, and Francis W. Wang, "Observations of shear-induced molecular orientation in a polymer melt using fluorescence anisotropy measurements," *Macromolecules* **24**, No. 12, pp. 3715-3717 (Communications to the Editor) (1991).

[193] T. M. Gregory, L. C. Chow, and C. M. Carey, "A mathematical model for dental caries: a coupled dissolution-diffusion process," *J. Res. NIST* **96**, No. 5, 593-604 (1991).

Metallurgy, E. Neville Pugh, chief

Stress Corrosion Cracking

In a collaboration between Richard E. Ricker and James L. Fink of NIST and A. K. Vasudevan of the Office of Naval Research, a study was made of the importance of precipitates in grain boundaries to the stress corrosion cracking of aluminum alloyed with small quantities of lithium, manganese, and copper. There were so many factors that were known to influence stress-corrosion cracking in precipitation-hardened alloys that the real challenge was to devise experiments in which one or two factors could be isolated for study.

The group chose to hold constant the matrix precipitates of a binary aluminum-lithium alloy. In turn, this technique held constant the yield strength. Then they could vary the size and volume percentage of grain-boundary precipitates. They also varied the matrix precipitate size and distribution with the grain-boundary precipitate size in a ternary aluminum-lithium-copper alloy so as to keep its yield strength constant at the same level as the binary alloy.

Using a variety of heat treatments and aging, the authors measured the strain-to-failure in aggressive environments—half-molar deaerated sodium chloride, and a brew prepared by adding to the sodium chloride solution pinches of sodium bicarbonate, sodium carbonate, and lithium chloride. These data they compared to similar measurements taken in a nitrogen-gas reference environment. At relatively low values of strain-to-failure in nitrogen, equal values of strain-to-failure occurred in the aggressive environments. At higher values in nitrogen, however, the aggressive-environment strain-to-failure values tapered off noticeably. Moreover, although both the binary alloy and the ternary alloy showed similar deviations, the effect on the binary was significantly more pronounced.[194]

The experiments furnished evidence that the type, size and density of grain-boundary precipitates strongly increased the susceptibility of aluminum-lithium alloys to stress corrosion cracking.

Graphite Fiber Composites in Electrolysis

George L. Cahen, Jr. and Glenn E. Stoner of the University of Virginia knew how to purge seawater of certain micro-organisms in 1990—this they could accomplish by ac electrolysis. But they wanted to know how graphite fiber-polymer composites would perform as electrodes in this type of system. To find out, they teamed with Gery R. Stafford of NIST. The group was optimistic, since graphite displayed good electrical conductivity, good chemical resistance, and generated a volatile oxidation product that consumed no electrical energy upon repolarization. But how would the composites perform?

Preliminary screening of candidate composites turned up some promising materials and some spectacular failures. Clearly a systematic study was needed.

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[194] R. E. Ricker, J. L. Fink, and A. K. Vasudevan, "On the stress corrosion cracking of Al-Li alloys: the role of grain boundary precipitates," *Metallurgical Transactions* **22A**, 264-267 (1991).

The authors prepared test electrodes, backed with nickel electroplating and embedded in a polyester resin so as to expose only a 4 cm by 0.25 cm face to the electrolysis solution, containing 2 % dehydrated seawater. A variety of electrical-current settings was used with random-oriented, parallel, and perpendicular fiber composites. Water absorption tests were performed on the composites, and voltage-time curves were obtained at fixed current densities, using the composite as the anode.[195]

Typically, after a period of time that varied with the composite, the measured potential at fixed current density would rise sharply for each material. Anodes with parallel fibers failed quickly, with the composite simply falling apart. Anodes with only the tips of fibers exposed to the solution lasted the longest.

Composites made with polyphenylene sulfide appeared to survive substantially better than those based on nylon, epoxy-butadiene, polyester, or epoxy.

The authors concluded that degradation of the cells occurred almost entirely at the anode, with loss of electrical contact to the conductive fibers. In the case of polyphenylene sulfide-fiber composites, integrity of the composite electrode could be expected to last for about 100 hours.

Laser Vaporization Mass Spectrometry

A dearth of reliable information on the behavior of materials at temperatures beyond 2000 K prompted Peter K. Schenck, David W. Bonnell, and John W. Hastie to investigate the coupling of laser vaporization and high-pressure molecular beam mass spectrometry as a means of obtaining thermochemical data on refractory materials.

Stripped to its bare essentials, the method chosen by the group was simple; blast the surface of a test sample with a powerful pulse of laser radiation, then peek at the debris as it whizzed through the mass filter of a mass spectrometer. However, estimating the temperatures reached on the surfaces of the samples and determining which chemical reactions might have given rise to the observed species was not so simple.

The authors tried the new technique on two types of materials; graphite, and the high-temperature superconductor, $YBa_2Cu_3O_x$ (YBCO). They used a neodymium-yttrium aluminum garnet laser pulsed at 20 Hz as the energy source. The laser delivered from 10 mJ to 40 mJ of energy in 10 ns at a wavelength of 532 nm to a spot on the sample that was about 0.25 mm in diameter, producing temperatures estimated from the time of flight of the vapor plume to be as high as 8000 K.

The mass spectrometer operated in a tank evacuated by a high-conductance (about 2000 L/s) pump, allowing free flow of the vapor plume. The group collected mass data with a time resolution less than 0.1 ms. By moving the samples under the laser beam, the authors could obtain time-resolved mass data averaged over many laser pulses. Alternatively, they could integrate time-gated spectral scans.

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[195] Gery R. Stafford, George L. Cahen, Jr., and Glenn E. Stoner, "Graphite fiber-polymer matrix composites as electrolysis electrodes," *J. Electrochem. Soc.* **138**, No. 2, 425-430 (1991).

The graphite targets yielded both neutral species and ions tentatively identified as C_1, C_3, C_1^+, C_2^+, C_3^+, and C_5^+ under direct bombardment of the samples by the laser. The YBCO samples produced a rich menu of molecular fragments: Cu, Cu^+, CuO^+, O_2, O_2^+, H_2O, CO_2, BaO, YO, CuBa, and YCu.

The authors declared the new technique an unqualified success. Both equilibrium and nonequilibrium effects were found, and the vapor plumes generated by the laser appeared to be nonhomogeneous both in space and in time; yet the method was productive and the results were subject to reasonble interpretation.[196]

Reactor Radiation, J. Michael Rowe, chief

The Reactor Radiation Division (RRD) was built on the concept of service. Possessing one of the few nuclear reactor research facilities in the Nation—with accompanying instruments that were unique—division personnel were keenly aware of the need to provide reactor run time for those scientists with experiments that required use of the facility. In some cases—both inside NIST and beyond its borders—scientific visitors could plan and conduct their own experiments with only minimal assistance from the division staff. There were plenty of requests for instrument time, however, in which the expertise existing among the staff was needed to make a fruitful experimental plan and carry it out.

The division explicitly welcomed visitors who needed only run time as well as those who desired to collaborate scientifically with its staff. In addition, division scientists maintained their own materials research programs involving the use of neutrons, and they continually looked to develop and maintain state-of-the-art instruments to take best advantage of the NIST reactor.

We have already described many experiments performed at the NIST reactor by personnel of other divisions, often in collaboration with one or more RRD colleagues. Specialized instruments associated with the reactor included neutron spectrometers, reflectometers, and diffractometers serving the thermal column, and a like set of devices—plus a small-angle neutron scattering capability—facilitating experiments that used the cold neutron source.

High-T_c Superconductors and Phonons?

A question asked immediately after the discovery of high-temperature superconductivity was: Does the origin of high-temperature superconductivity involve the crystal lattice, as the Bardeen-Cooper-Schrieffer theory indicated for conventional (low-temperature) superconductors?

There seemed to be as many answers to that question as there were high-T_c materials. Certain materials with T_c values near 30 K—lanthanum-strontium cuprate and barium-potassium bismuthate, for example—showed substantial isotope effects, indicating that the lattice indeed played a role in the superconductive interaction. Other materials, particularly those with transition temperatures above 77 K, showed no isotope effect at all.

[196] P. K. Schenck, D. W. Bonnell, and J. W. Hastie, "Laser vaporization mass spectrometry of refractory materials: graphite and $YBa_2Cu_3O_x$," *J. Vac. Sci. Technol.* A7, No. 3, pp. 1745-1749 (1989).

A team of investigators including Jeffrey W. Lynn, Dan A. Neumann, and John J. Rush of the Reactor division and I. W. Sumarlin, J. L. Peng, and Z. Y. Li of the University of Maryland, aware that inelastic neutron scattering provided good insight into lattice resonance modes, or phonons, conducted a series of such measurements on a 43 g sample of polycrystalline $Nd_{1.85}Ce_{0.15}CuO_4$ (NCCO).

In the range of neutron energy up to 100 meV, the group found structure that they attributed to generalized phonon density of states peaks at 13 meV, 51 meV, and 65 meV. Tucked away in the results they also discovered smaller phonon structure. Comparing their results with those obtained in superconducting tunneling experiments, they found agreement at 14 meV, 32 meV, and 40 meV, indicating that, indeed, phonons did play a part in the superconductive interaction in NCCO.[197]

In the meantime, Russell C. Casella extended his earlier discussion of high-temperature superconductivity to account for anisotropy observed in electron tunneling experiments in $Bi_2Sr_2CaCu_2O_8$ (BSCCO). Previously, Casella had proposed a multiple-energy-gap explanation for the dependence of T_c in certain compounds containing layers of CuO_2 upon the number of layers.

In tunneling measurements on single-crystal BSCCO, the ratio of the superconducting energy gap to the transition temperature had been evaluated as 6.2 ± 0.3 when the current was injected in the *ab* plane and as 3.3 ± 0.5 when the current followed the *c* axis. Casella employed a model in which double intermediate boson exchange took place between fermions in two bands. The consequences of his model were consistent with current experimental results and allowed for specific experimental tests.[198]

Vibrational Modes in Fullerene

R. L. Cappelletti spent a portion of his sabbatical leave from Ohio University at NIST, investigating fullerite, an interesting molecule with the formula C_{60}. In the work, he collaborated with John R. D. Copley and William A. Kamitakahara of NIST and with Fang Li, J. S. Lannin, and D. Ramage of Penn State University.

The shape of the C_{60} molecule and its relatives was nearly spherical, with all atoms on the surface, forming cage-like structures known as "Buckey balls" or "Buckminster Fullerene." Some 46 distinct vibrational frequencies were possible for the C_{60} structure. Previous observations of the molecule by infrared and Raman spectrsocopy were limited to only 14 of the frequencies, but all participated in neutron scattering.

The team purified a 640 g polycrystalline sample of C_{60} and conducted scattering measurements using a modified three-axis spectrometer at the NIST reactor. The sample was held at 10 K during the 6-day run.

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[197] J. W. Lynn, I. W. Sumarlin, D. A. Neumann, J. J. Rush, J. L. Peng, and Z. Y. Li, "Phonon density of states and superconductivity in $Nd_{1.85}Ce_{0.15}CuO_4$," *Phys. Rev. Lett.* **66**, No. 7, 919-922 (1991).

[198] R. C. Casella, "A theoretical model for the tunneling-gap anisotropy observed in layered copper-oxide high-temperature superconductors," *Solid State Commun.* **78**, No. 5, pp. 377-379 (1991).

The neutron scattering spectrum, taken from 0 meV to 240 meV, was complex. It included three prominent peaks associated with vibrational density-of-states measurements in graphite, along with other structure attributed to the infrared-active and Raman-active modes as well as other vibrational modes predicted by theory. In certain respects, however, the data were not in accord with available theoretical predictions, leading to the suggestion that theoretical treatments might be improved on the basis of this type of measurement.[199]

Low-Temperature Motion of Protons in Scandium

A neutron-scattering experiment on purified, single-crystal scandium provided a diverse group of scientists with new information on the motion of hydrogen within the scandium lattice. Norman F. Berk, John J. Rush, and Terrence J. Udovic of NIST collaborated on the project with I. S. Anderson of the Paul Scherrer Institute of Switzerland, R. G. Barnes of Iowa State University, A. Magerl of the Laue-Langevin Institute of France, and D. Richter of the Institute for Research in Solid State and Nuclear Science in West Germany.

The group knew that hydrogen, when dissolved in hexagonal-close-packed rare-earth metals, displayed unusual short-range ordering, with consequences that were noticeable in certain physical properties of the material. They hoped to excite a "hopping" mode of hydrogen within the scandium lattice that would reveal to them some details about the localized motion.

Accordingly they loaded one single crystal of scandium with 5 % to 20 % concentrations of hydrogen, left a second crystal unhydrogenated, and subjected both to neutron irradiation at the Laue-Langevin Institute in Grenoble, France. The difference spectra, obtained at temperatures of 300 K, 125 K, 100 K, 70 K, and 50 K showed a sharp spectral line whose width surprisingly exhibited a noticeable minimum near 100 K. Below that temperature, the linewidth increased approximately as $1/T$, the first such observation seen in the system.

The authors took the results as an indication of nonadiabatic behavior in the hydrogen motion. The data also indicated extremely rapid hopping rates, more than 10^{10} per second. They discussed their results in terms of the locations of the hydrogen atoms in the scandium lattice and the energetics of the hydrogen motion.[200]

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[199] R. L. Cappelletti, J. R. D. Copley, W. A. Kamitakahara, Fang Li, J. S. Lannin, and D. Ramage, "Neutron measurements of intramolecular vibrational modes in C_{60}," *Phys. Rev. Lett.* **66**, No. 25, pp. 3261-3264 (1991).

[200] I. S. Anderson, N. F. Berk, J. J. Rush, T. J. Udovic, R. G. Barnes, A. Magerl, and D. Richter, "Rapid low-temperature hopping of hydrogen in a pure metal: the ScHx system," *Phys. Rev. Lett.* 65, No. 12, pp. 1439-1442 (1990).

Building and Fire Research Laboratory

The building research and fire research organizations were separate within NBS from 1974, when the Federal Fire Prevention and Control Act directed the Bureau to create a Center for Fire Research (see A Hectic Decade For NBS Fire Science in Ch. 4), until Director John Lyons established the new NIST organization in 1991. At that time, Richard N. Wright was appointed director and Jack E. Snell was made his deputy.

Structures, Hai S. Lew, chief

Abating Earthquake Hazards

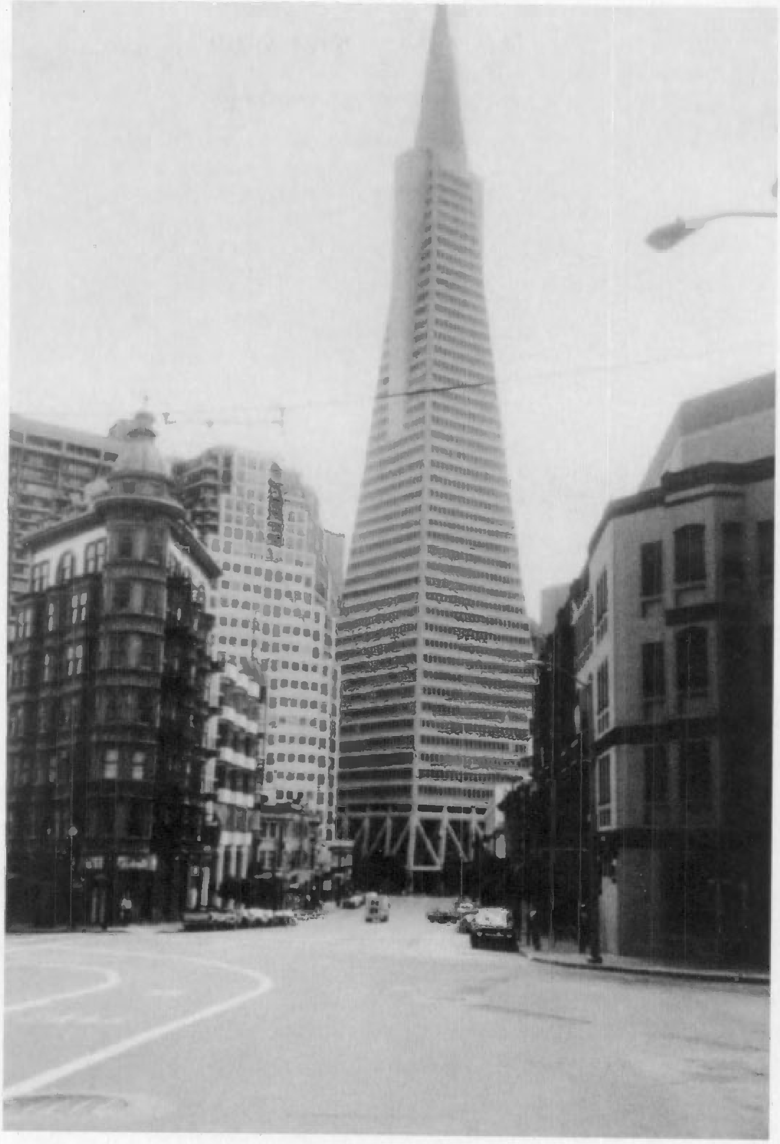
On October 17, 1989, the "Loma Prieta" earthquake shook the San Francisco Bay area. The epicenter of the quake was located about 90 km southeast of the city along the San Andreas fault line. Because of the "shaky" history of the Bay area, many buildings had been instrumented with accelerometers to record their motion in response to earthquakes. Thus the Loma Prieta event provided NIST with an excellent opportunity to compare the recorded responses to the strong shaking of the earthquake with building-response predictions derived from low-level vibrations. Richard D. Marshall and Long T. Phan of NIST collaborated with Mehmed Çelebi of the U.S. Geological Survey on the project.

The team studied five buildings from the earthquake region. These were selected on the basis of several criteria:

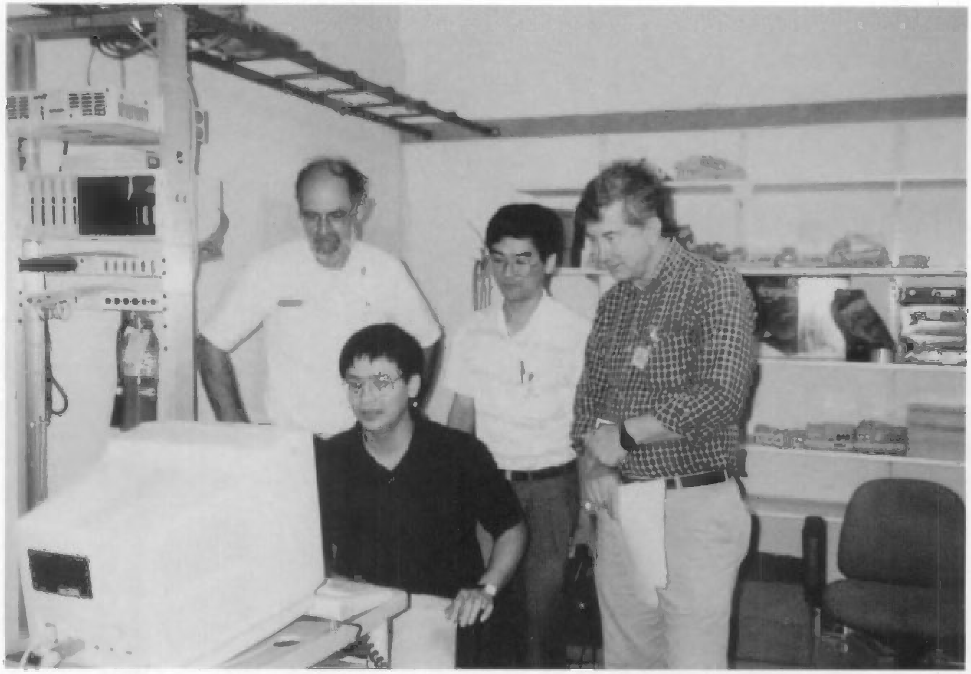
- Availability of accelerometer records showing strong motion as a result of the earthquake.
- No visible signs of structural damage from any earthquake.
- Accessibility to the building for ambient vibration studies.
- Availability of detailed structural drawings and knowledge of soil conditions at the building site.
- Adherence of the building to current construction codes.
- Contribution to the variety of construction materials and methods desired in the investigation.
- Degree of complexity in the analytical model to be used to describe the building response to earthquakes.

Two organizations had instrumented buildings in the area with force balance accelerometers: the California Division of Mines and Geology, through its "Strong Motion Instrumentation" program; and the U.S. Geological Survey, through its Engineering Seismology Branch. The accelerometers produced time histories of velocity and displacement at various positions within each building.

NIST Structures Division engineers H. S. Lew and Nicholas J. Carino investigated structural damage to the two-tiered Nimitz Freeway, which collapsed during the 1989 Loma Prieta Earthquake.



View to the southeast of the landmark Transamerica building in San Francisco, 97 km from the epicenter of the Loma Prieta earthquake. The Transamerica was built on a 9-ft thick concrete mat foundation with no piles. It was instrumented by the U.S. Geological Survey.



NIST scientists Richard D. Marshall (left) and Long T. Phan (seated) monitor real-time measurements of accelerations of a building resulting from ambient vibrations, along with Chang H. Hyun (standing, center) of the Korea Institute of Nuclear Safety and Mehmed Çelebi of the U.S. Geological Survey.

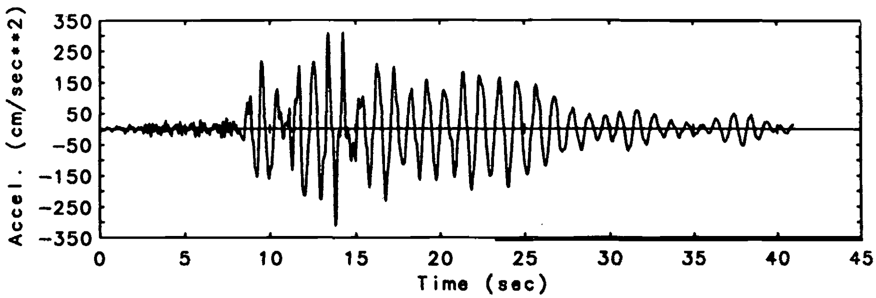
The five buildings chosen for the study were the 13-story California State University Administration Building at Hayward, the 12-story Santa Clara County Office Building at San Jose, a 6-story commercial office building in San Bruno, the 49-story Transamerica Building in San Francisco, and the 30-story Pacific Park Plaza in Emeryville.

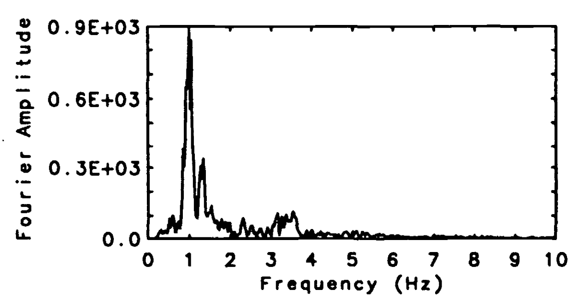
Once the required structural and Loma Prieta records were in hand, the team conducted ambient vibration measurements in each building, using its existing accelerometer array to record building response to ordinary, everyday vibration—mostly from the effects of wind.

Both the recorded strong-motion data and the ambient vibration responses were analyzed to identify relevant dynamic characteristics of each building; then the two sets of analyses were compared.

The team found that, with suitable signal conditioning, the force-balance accelerometers produced reliable ambient vibration measurements. This finding would allow the use of the accelerometers to identify the main modes of building vibration. Several other conclusions were reached as well; these related to details of the building construction and to the nature of the soils on which the buildings were constructed.[201]

[201] R. D. Marshall, Long T. Phan, and M. Çelebi, "Measurements of structural response characteristics of full-scale buildings: comparison of results from strong-motion and ambient vibration records," *NISTIR 4884*, October 1992, 74 pp.





(Top figure) Acceleration-time graph in the east-west direction at the center of the roof of a 6-story office building in San Bruno, California during the Loma Prieta earthquake. (Bottom figure) Fourier spectrum derived from the top figure, showing the major vibrational frequencies of the building.

As a consequence of the Loma Prieta earthquake, President Bush issued Executive Order 12699 on January 5, 1990. Entitled "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction," the order was intended to reduce risks to the lives of occupants of buildings owned by the Federal government and to persons who would be affected by failure of such buildings in earthquakes. The order helped secure new building codes in earthquake-prone areas.

"The future of lifeline earthquake engineering depends, in large part, upon our ability to develop and communicate new concepts and ideas for design, construction, operation, and post-event restoration of lifelines." So read the Foreword to the *Proceedings of the 4th U.S.-Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems,* held in Los Angeles from August 19-21, 1991. Robert D. Dikkers of NIST's Structures division served on the organizing committee for the workshop, which featured contributions from earthquake scientists from many organizations in Japan and America.

Dikkers offered to the workshop participants a discussion of the U.S. response to the *National Earthquake Hazards Reduction Act of 1977* (PL 95-124)—updated by Congress in 1990—which requested the Federal Emergency Management Agency to oversee the formulation of a plan aimed at design and construction standards for lifelines. In the context of the Act, lifelines included electrical power, gas and liquid fuel, telecommunications, transportation, and water and sewer.

The 1990 reauthorization of PL 95-124 directed FEMA to consult with NIST on the formulation of an action plan to create standards for the preservation of lifelines. Dikkers and his colleagues from industry, government, and academia collaborated to create a comprehensive response to that request.[202]

Locating Reinforcing Bars in Concrete

An important step in evaluating the load capacity of an existing reinforced concrete structure was the capability of locating the number and configuration of the steel rods used to strengthen the concrete. Particularly under the types of stresses arising in earthquakes were the details of the reinforcing significant. For years, sensing devices had been available to detect the presence of reinforcing rods and their locations within the concrete in a nondestructive fashion, but no U.S. industrial standards existed for these so-called "covermeters" when Nicholas J. Carino set about to characterize them in 1992.

Carino conducted experiments comparing the capabilities of two types of covermeters available commercially—one based on measurements of magnetic reluctance and the other on eddy current observations. He examined the relationships between meter reading and "cover thickness," the thickness of concrete covering the reinforcing rod, and the change in reading occasioned by a change in rod diameter. He also investigated the limits for useful response of the meters to multiple bars, to ends of bars, and to spliced bars.

In his report, Carino offered simple descriptions of the operation of the two types of covermeters, summarized the results of his many tests, made recommendations for developing standard test methods for the meters, and presented suggestions for enhancing the effectiveness of then-existing devices and for improvements in the design of such equipment.[203]

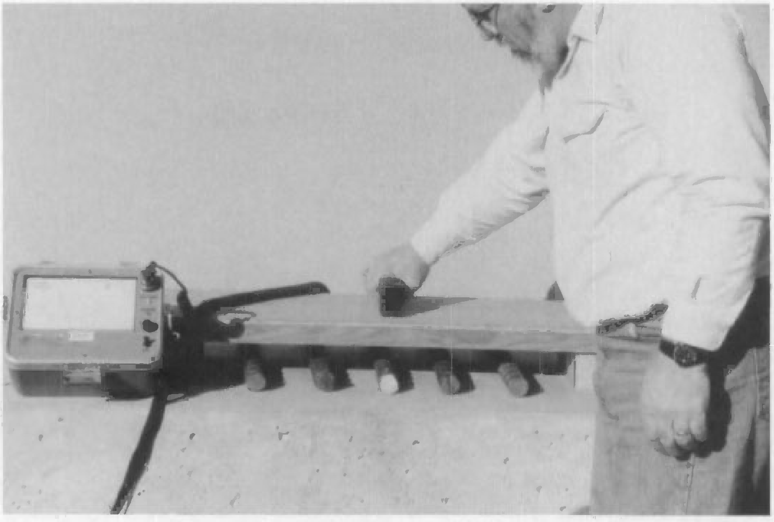
Building Materials, Geoffrey J. Frohnsdorff, chief

Detecting Surface Defects

In certain industries—for example, automobiles and appliances—a perfect or near-perfect surface finish was vital to the commercial value of the manufactured item. Unfortunately, lumps and craters were the constant companions of coatings that

[202] Robert D. Dikkers, "Development of seismic design and construction standards for lifelines," *NIST Special Publication 840*, August 1992, 481 pp.

[203] Nicholas J. Carino, "Performance of electromagnetic covermeters for nondestructive assessment of steel reinforcement," *NISTIR 4988*, December 1992, 127 pp.



NIST Structures Division engineer Nicholas J. Carino operated a covermeter for locating reinforcing rods in reinforced concrete. The device operated by detecting magnetic reluctance.

satisfied the criterion of minimal volatile organic content, and these defects were hard to spot. Ordinary visual inspection proved unsatisfactory, and profiling styli were unrealistic in time and expense. However, Dale P. Bentz and Jonathon W. Martin adapted a thermographic method that was up to the task.

Relying on previous experience with thermography, the two scientists developed a theory for use of the technique for coating-defect detection, then devised a method to automatically survey the surface finish of test samples. A key element of the method was to create a temperature gradient of 20 °C to 30 °C between the coating and its environment. A thermographic camera then could be coupled with a computer-driven image processor for digitization of the surface appearance. Surface defects were readily apparent in the thermographic images, primarily because of the difference in coating thickness at the defect. The method was attractive—it was quick, simple, and automatic.[204]

Evaluating Roofing Materials

A research effort conducted by the U.S. Army Construction Engineering Research Laboratories, attempting to identify types of roofing that could be easily installed, durable, and low in maintenance, was materially aided by personnel from NIST. D. M. Bailey, Walter J. Rossiter, and James F. Seiler assisted Army personnel in the evaluation of three types of bitumen-based roofing at Fort Polk, Louisiana. The properties of the roofing materials were tested prior to installation on one of the buildings; at the end of each year for 3 years, the roofs were inspected for obvious damage and test samples were taken from the roofs for comparison with the original samples.

[204] D. P. Bentz and J. W. Martin, "Thermographic imaging of surface finish defects in coatings on metal substrates," *Materials Evaluation* **50**, No. 2, pp. 242-246 (1992).

The NIST team found the roofing materials to be satisfactory in terms of wear on the building and to be usefully durable as well.[205]

Predicting Service Life of Concrete

Very costly decisions on the repair or replacement of concrete structures relied upon evaluations by inspectors of the serviceability of the structure. In order to place such evaluations on a sounder basis, James R. Clifton of NIST and James M. Pommersheim of Bucknell University collaborated on a study of the methods involved in lifetime predictions.

Most evaluative methods assumed that corrosion was the principal cause of degradation of concrete structures. To predict the remaining useful life, the inspector typically would examine the concrete to determine its present condition, then seek the cause of any perceived decay. Extrapolating the progress of the degradation, the inspector would then estimate the time when the structure would reach a stage where repair or replacement would become necessary.

Both modeling and measurements were used in forecasting the life of concrete. Both approaches assumed that degradation would follow a known path: an initiation period during which attacking ions would slowly penetrate the concrete to reach its reinforcing steel members and commence the process of chemical decay; and a propagation period during which the chemical decay would progress until the concrete structure lost its strength. The authors summarized the steps recorded by various writers in modeling the corrosion process, as well as polarization resistance measurements used to monitor the growth of corrosion currents.

By conducting accelerated degradation tests, the inspecting authority could evaluate various corrosion routes, determine rate-controlling steps, and obtain estimates of useful lifetimes. The authors noted that such testing, while expensive, could well be justified to improve useful-life predictions of expensive concrete structures.[206]

Building Environments, James E. Hill, chief

Thermal Bridges in Buildings

The building industry was well aware that certain features in the construction of buildings provided easy paths for the flow of heat energy between the inside of the building and the outside. These energy pathways were known as "thermal bridges." They included such items as ceiling fasteners in built-up roofs, metal studs in insulated masonry walls, steel casings at window frames, the joints between the roof and the side wall, and the joints between the floors of the building and its side walls. In every case, they provided a kind of "short circuit" of material with relatively high thermal

[205] D. M. Bailey, W. J. Rossiter, and J. F. Seiler, Jr., "Three-year field test summary for experimental modified bitumen roofing at Fort Polk, LA," *FM-93/05*, December 1992, 34 pp.

[206] James R. Clifton and James M. Pommersheim, "Methods for predicting remaining life of concrete structures," *NISTIR 4954*, November 1992, 24 pp.

conductivity that reduced the effectiveness of the insulation installed in the building envelope. Steady-state analysis of thermal bridges typically put the increase in energy transmission on their account at 10 % to 20 %. Douglas M. Burch, George N. Walton, and Betty A. Licitra of NIST collaborated with John E. Seem of Johnson Controls Corporation to show that a time-dependent analysis of thermal bridges raised the steady-state estimates substantially.

For their study, the authors configured a modest two-story office building constructed according to current practice. Then they calculated the conduction transfer function for the building without considering the thermal bridges. Finally, they repeated the calculation using a two-dimensional, finite-difference analysis to evaluate the dynamic heat-flow contribution of the thermal bridges. The overall heat transfer coefficient through the outer envelope of the building increased by an impressive 33 % when the contributions of the thermal bridges were included in the analysis.[207]

Improved Buoys for Water Safety

In the early 1990s, the U.S. Coast Guard—as a correspondent with the International Association of Lighthouse Authorities (IALA)—was concerned that the imperfect base of knowledge of visibility of navigational buoys was hampering the adoption of improved international standards for their shapes and color-coding. The IALA suggested that standard shapes and colored markings could identify the port and starboard limits for channels, the deepest water in an area, especially dangerous or especially safe areas, and special features of particular locations. The trouble was, nobody was sure how well any particular designs could be seen by boaters. To help the Coast Guard evaluate the effectiveness of some of the designs before they invested significant effort and expense in new buoys, Belinda L. Collins and Philip A. Sanders reviewed available research on buoy visibility and undertook experiments to enhance the state of knowledge on the topic.

In a *NIST Interim Report,* Collins and Sanders reviewed existing IALA standards for buoys, including type, shape, color, and geometrical topmarks. They also reviewed the lore surrounding the use of buoys for daytime navigation—problems caused by tides, marine growths, sun-fading, open-air deterioration, and color-blindness in navigators.

As their own contribution to the visibility question, Collins and Sanders hit upon the photography of 8 % scale models of test buoys, followed by evaluation of the images by a panel of observers. Ten different buoy configurations were prepared by Robert E. Stachon of the Groton, Connecticut, Coast Guard facility. Rosemary Porterfield and James R. McMahon, officials at Black Hills Regional Park, a facility of the Maryland-National Capital Park and Planning Commission, made their 200 hectare lake available for the photography. Some 13 slides were prepared for each scale model to simulate views from typical boating distances of 0.2 km to 4 km, and in a variety of lighting and background conditions.

[207] D. M. Burch, J. E. Seem, G. N. Walton, and B. A. Licitra, "Dynamic evaluation of thermal bridges in a typical office building," *ASHRAE Transactions: Research 98, Part 1,* pp. 291-304 (1992).

The resulting photographic slides were first shown to 17 observers denoted as "naive," then again to 10 trained observers at Coast Guard Headquarters in Washington. The observers determined the distances at which the scale buoys could be identified under the various experimental conditions, relying on shape, color, and topmarks.

Interpretation of the results required careful analysis, which the authors detailed in their report. Their conclusions included the following:

- The presence of topmarks did not increase the visibility of the buoys tested for distances beyond 0.8 km—color was substantially easier to recognize than topmarks when viewed with front lighting.
- In back lighting and twilight conditions, visibility decreased substantially, with or without topmarks.
- Red colors were visible at greater distances than greens.
- Painted bands in contrasting colors appeared to be effective visual aids for buoy recognition. [208]

New Lamps for Old

The introduction of new, more compact fluorescent lamps for commercial and domestic use in the United States and Canada brought longer lamp life, reduced energy use, and lower operating costs. These benefits were most welcome. However, the new lamps also brought questions about their performance compared to the older lamps they replaced—such concerns as their response to extremes of heat and cold, sensitivity to lamp position and mechanical shock, and visibility of flicker.

In conjunction with Michael J. Ouellette of the National Research Council (NRC) of Canada, Belinda L. Collins and Stephen J. Treado of NIST began in 1992 to resolve the outstanding uncertainties regarding the performance of the compact lamps. The trio of scientists decided first to test lamp response to variation in ambient temperature.

In a large NIST environmental chamber, 12 three-lamp sets of various types of the compact fluorescents and a control set of incandescent lamps were subjected to six different temperatures in the range 45 °C to −18 °C. Each lamp had been operated for 100 hours at the NRC for pre-conditioning. Photocells positioned near each lamp monitored luminous output and flicker. Extensive measurements were made by the group—of time-to-ignition, light output vs time for each lamp at each temperature, power use of each lamp, flicker characteristics, and harmonic distortion.

The authors found that the temperature of the space in which the lamps operated generally affected their performance in a big way—in some cases, the lamps failed to operate, in others the light output dropped to 10 % of the value at 25 °C. A notable exception were lamps with outer glass enclosures, which performed well at low temperatures. On the other hand, the fluorescent lamps were noticeably more efficient than the incandescent lamps when measured near 25 °C.[209]

[208] Belinda L. Collins and Philip A. Sanders, "Evaluation of the visibility of buoys and topmarks," *NISTIR 4756*, March 1992, 68 pp.

[209] Belinda L. Collins, Stephen J. Treado, and Michael J. Ouellette, "Evaluation of compact fluorescent lamp performance at different ambient temperatures," *NISTIR 4935*, December 1992, 47 pp.

Moisture Accumulation Under Roofs

Department of Housing and Urban Development officials thought they might have a problem with moisture condensation in manufactured homes. A 1984 survey of several dozen manufactured homes throughout the United States turned up moisture problems in about one-third of the cases. A later survey in Canada showed similar results.

Why should moisture particularly concern residents of manufactured homes? For one thing, HUD did not require ventilation of the space below the roof to the outside air, as many conventional homes possessed. For another, manufactured homes generally were smaller than conventional homes built for the same number of occupants, thus concentrating the moisture generated by normal household activities into a smaller space; in cold weather, unavoidable exchange of air between the living space of the home and its roof cavity carried the moist air into contact with the cold roof, resulting in increased humidity and, perhaps, accumulation of water.

At the request of HUD, Douglas M. Burch of NIST fired up his computer and analyzed the problem. He assumed a layered roof structure for which he sought the time-dependent moisture content. Other assumptions included:

- Moisture transfer was driven by temperature and humidity gradients.
- Moisture transfer was one-dimensional.
- Heat transfer was temperature independent.

Burch prepared a computer program—which he called MOIST—to solve the problem, using standard heat-and moisture-transfer equations. Among many other findings, a significant one was the effect of indoor humidity levels on the moisture content of roof fibers. In cold climates, the calculations indicated that fiber saturation would occur above about 40 % relative humidity during the three coldest winter months if no roof-cavity ventilation to the outdoors was available. Another calculation showed that, in hot, humid climates, outdoor ventilation of the roof cavity could allow the sub-roof humidity to exceed 80 %, favoring the growth of molds and mildew.

Burch's prescription for manufactured homes?

1. In cold climates, install vapor barriers in the ceilings, seal all openings in the ceilings, and vent the roof cavity to the outdoors.
2. In hot, humid climates, do not ventilate the roof cavity to the outdoors.[210]

Fire Safety, Andrew J. Fowell, chief

Predicting Fire Danger: HAZARD I

On March 25, 1990, 87 people died in a fire in the "Happyland Social Club" in the Bronx, New York. Evidence found on the scene indicated that the fatal blaze was the result of arson—gasoline appeared to have been poured and lighted near the club

[210] Douglas M. Burch, "Controlling moisture in the roof cavities of manufactured housing," *NISTIR 4916*, November 1992, 43 pp.

entrance, dooming many club patrons to death from smoke inhalation or from burns. A few days later, the New York City Fire Department asked NIST to help identify the reasons why the fire resulted in so many deaths; what changes on the scene could have reduced the death toll?

NIST was ready for the NYFD request with a computerized program that could evaluate structure fires on the basis of the nature of the structure, the types of fire safety equipment on hand, and the progress of the conflagration. The program was called the HAZARD I Fire Hazard Assessment Model. Quickly, a NIST fire research team collected on-site information on the circumstances surrounding the fire for analysis with HAZARD I. On the basis of the analysis, Richard W. Bukowski and Robert C. Spetzler prepared a report for the NYFD which they later summarized in a journal article.

The authors used HAZARD I to process the data gathered at the fire site and to predict the progress of the fire. The prediction matched closely the descriptions given by witnesses to the blaze, including the elapsed time until conditions in the club became inconsistent with life. The program also identified two key points regarding the high mortality rate from the fire:

- No automatic sprinklers were operating in the building—such equipment would have stopped or severely restricted the loss of life.
- The use of non-combustible finishes on the inner surfaces of the building would have denied the fire the fuel it needed to build to the magnitude that took so many lives.

Bukowski and Spetzler pointed out that HAZARD I, with its relatively simple calculational tools such as algebraic equations and simple models, could effectively complement the more complex zone and field models already in use in fire safety engineering. It could identify factors leading to high fire-death tolls and point to strategies for avoiding similar fires in the many social clubs operating within large cities.[211]

Bukowski also presented a strategy for the development and implementation of performance-based fire codes for international use. His presentation took place during a forum for International Cooperation on Fire Research held in Sydney, Australia, October 18-20, 1992. The first step in the process, according to Bukowski, was agreement on a common set of goals, followed by agreement on suitable predictive tools. Ultimately, the procedure could be expected to lead to estimation of the performance of any building under the stress of fire.[212]

Evacuating the Handicapped

Rising concern within the U.S. General Services Administration for the safety of handicapped persons in burning buildings led to consideration by NIST researchers of the feasibility of using elevators to evacuate such individuals. In most countries, elevators were shut down during fire emergencies. By 1992, the NIST team, including

[211] R. W. Bukowski and R. C. Spetzler, "Analysis of the Happyland Social Club fire with HAZARD I," *J. Fire Prot. Eng.* **4**, No. 4, 117-131 (1992).

[212] R. W. Bukowski, "Toward the goal of a performance fire code," *Fire and Materials* **15**, No. 4, 175-180 (1991).

John H. Klote, Daniel M. Alvord, Bernard M. Levin, and N.E. Groner, completed a report to GSA that addressed the installation of elevator systems in buildings, design changes needed to make them available during fires, and human factors affecting their use. The study indicated that re-designed elevators could be of considerable help both in fires and in other types of emergencies.[213]

Fire Science, Richard G. Gann, chief

One of the greatest challenges to fire researchers was the need to place fire tests on a solid scientific footing and to develop computer models to reduce the amount of large-scale testing. A fully furnished room presents a very large number of potential ignition scenarios and hence a similar mumber of fire-growth alternatives.

The tradition of fire testing was to devise simple bench-top tests. Since these could not generally be related to actual fire conditions, the technique grew to incorporate full-scale models of rooms or buildings, which then were burned to obtain one-time data.

Beginning in the 1970s, computer modeling began to be feasible. The HAZARD I and CFAST models developed at NBS incorporated material properties, design data, and testing results, including the use of such devices as the cone calorimeter—developed at the Bureau.

Fire Danger and Heat Release Rate

During the 1990 meeting of the Fire Retardant Chemicals Association, Vytenis Babrauskas and Richard D. Peacock presented evidence, based upon years of correlating damage caused by fires with the various data characterizing them, that the single most important factor in assessing fire hazards was the heat release rate.

To support their assertion, the two scientists cited case histories illustrating that, although toxic gases were the primary cause of death in fires, it was heat release rate, not the toxicity of the product gases, that was the best predictor of fire hazard. Such other observables as delays in ignition time proved to be of only minor importance.[214]

Fire at Sea

Fire damage control, important everywhere, was crucial on board combat ships in wartime. Simple survival, let alone successful effort in battle, depended upon freedom from crippling fires.

During 1989, a study team including NIST's Emil Braun, Darren L. Lowe, and Walter W. Jones, collaborators Patricia Tatem and Jean Bailey of the Naval Research Laboratory in Washington, DC and Richard Carey of the David Taylor Naval Ship Research and Development Center in Annapolis, Maryland, conducted a series of fire tests on the USS Shadwell, a decommissioned Naval vessel, to help improve shipboard fire control procedures.

[213] J. H. Klote, D. M. Alvord, B. M. Levin, and N. E. Groner, "Feasibility and design considerations of emergency evacuation by elevators," *NISTIR 4870,* February 1992, 126 pp.

[214] V. Babrauskas and R. D. Peacock, "Heat release rate: the single most important variable in fire hazard," *Fire Safety Journal* **18**, No. 3, 255-272, 1992.

Four full-scale tests were performed on the Shadwell, using two different fuels, diesel oil and polyethylene beads, and two different ventilation systems. The results were analyzed to determine fuel mass loss, progress of the fires in the burn compartments, and changing conditions in compartments separated from the burn areas. In the burn compartments, a load platform tracked the fuel mass, thermocouple thermometers tracked the fire progress, and gas analyzers monitored O_2, CO, and CO_2. Gas and smoke concentrations were observed in two passageways and on the main deck. The effects of opening or closing doors and vents connecting various areas were examined. A smoke ejection system was set up to remove combustion products from surrounding areas. The data showed that within 6 to 7 minutes, the ejection system, coupled with the provision of adequate ventilation of test passageways and compartments, removed enough of the combustion products to remove the threat to life.

A NIST model for fire growth and smoke transport, known as CFAST,[215] was used to simulate the fires and predict the temperature distributions and the effect of ventilation on the fire progress and smoke concentrations.

Results of the experiments indicated that sealing the compartments containing the fires and ventilating adjoining areas would provide the most effective control of the fire. The authors also found that the CFAST program successfully predicted the shipboard environment under fire conditions.[216]

A New Tool for Flame Studies

Nelson P. Bryner, Cecilia D. Richards, and William M. Pitts published a description in 1992 of a new instrument designed to give unprecedented measurement access to flame jets and plumes. The device, a Rayleigh light scattering facility that combined laser diagnostics with a cylindrical "clean room" test space of diameter 2.4 m and height 2.4 m, gave the authors the ability to examine the process of mixing in free jets and buoyant plumes.

Key to the success of the new device was the minimization of interference from glare and Mie scattering by the suppression of background light and dust particles in the test cylinder. For the first time, the facility permitted scattering measurements to be made in momentum-driven flows.[217]

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[215] W. W. Jones and G. P. Forney, *NIST Tech Note 1283* (1990).

[216] Emil Braun, Darren L. Lowe, Walter W. Jones, Patricia Tatem, Jean Bailey, and Richard Carey, "Comparison of full scale fire tests and a computer fire model of several smoke ejection experiments," *NISTIR 4961*, November 1992, 43 pp.

[217] N. P. Bryner, C. D. Richards, and W. M. Pitts, "Rayleigh light scattering facility for the investigation of free jets and plumes," *Rev. Sci. Instrum.* **63**, No. 7, 3629-3635 (1992).

Fire Hazards from Burning Furniture

The leading cause of residential fire deaths in the late 1980s was fire in upholstered furniture. From 1983 to 1987, one death in four came from that source. A majority of those fires originated from smoking materials, either pipes or cigarettes. Disturbed by the uncertainties in statistical data regarding the relation between the hazard created by a fire and the manner of ignition, Thomas G. Cleary, Thomas J. Ohlemiller, and Kay M. Villa designed an experiment to further examine the fire danger in upholstered furniture.

The fire scientists subjected a set of upholstered chairs made from five different combinations of foam and fabric to five types of ignition source:

- Burning cigarettes.
- Small flames such as a burning match might create.
- An incandescent lamp, typical of a reading aid.
- A space heater, producing primarily radiative energy.
- A large flame source such as an arsonist might choose.

The experiment was conducted in a furniture calorimeter, which captured the plume from the burning chairs; measurements included heat release rate, oxygen usage and rate of production of gaseous CO and CO_2, and rate of change of the chair mass.

The authors realized the limitations of their experimental procedure; they could not hope to duplicate the myriad types of fire leading to the death statistics. However, they were confident that heat release rate would best correspond to the fire hazard associated with a particular type of burning. They also relied upon HAZARD I, a methodology developed at NIST over the course of many years of fire research.

Of the total of 25 combinations of chair type and ignition source, 15 resulted in ignition and burning of the chair. Only one chair type was ignited by the lamp, only one by the cigarette. The "match" ignited three types of chair. Predictably, the space heater and the gas burner ignited all the test chairs. The progress of the burning—time to ignition and time to peak heat release—varied with both chair type and ignition source.

Using the HAZARD I modeling program, the authors assessed the likely fatality rate in their tests. To use the program, it was necessary for them to specify a number of conditions accompanying the fire: the type of home involved; the location of the chair; the age, mobility, and location in the dwelling of the victim; the time of day; and the presence or absence of a smoke detector. The rate and magnitude of heat release and the rate and nature of release of CO and CO_2 constituted the measured input data.

It is significant that the HAZARD I program predicted no deaths in the NIST experiment if a working smoke detector was in use. Without a smoke detector to warn the occupants of the simulated dwelling, about 45 deaths would have occurred to the 60 people—in family groups of baby, mother, father, and grandparent—involved in the 15 fires. The "arson-type" burner would have claimed 20 of the victims, and the space heater another dozen. The "match" and the "reading lamp" together would have killed another 13 occupants. Only the cigarette, relatively ineffective as an ignition source in this experiment, would have spared any humans occupying the fictitious home.[218]

A New Particulate Generator

Seeking the development of an effective tool for the study of small particulates in flames, a research team including Thomas G. Cleary, George W. Mulholland, Lewis K. Ives, and Robert A. Fletcher of NIST and J. W. Gentry of the University of Maryland used the tools of transmission electron microscopy (TEM) and laser microprobe mass spectroscopy (LAMMS) to investigate the particles produced in combustion aerosols.

For their study, the team adapted a laminar diffusion burner developed at NIST by Robert J. Santoro, Hratch G. Semerjian, and R. A. Dobbins in 1983. They used acetylene as the fuel, operating the burner at sufficiently low fuel flow rates that no visible sooting occurred.

Examination of the burner flame with the NIST TEM capability showed particle sizes clustered tightly around 7 nm. Observations with the LAMMS technique indicated the presence of carbonaceous materials as well as phosphorus and sulfur compounds originating in impurities in the acetylene. The authors stated that theirs was the first known steady-state generation of essentially monosized ultrafine aerosols in a diffusion flame.[219]

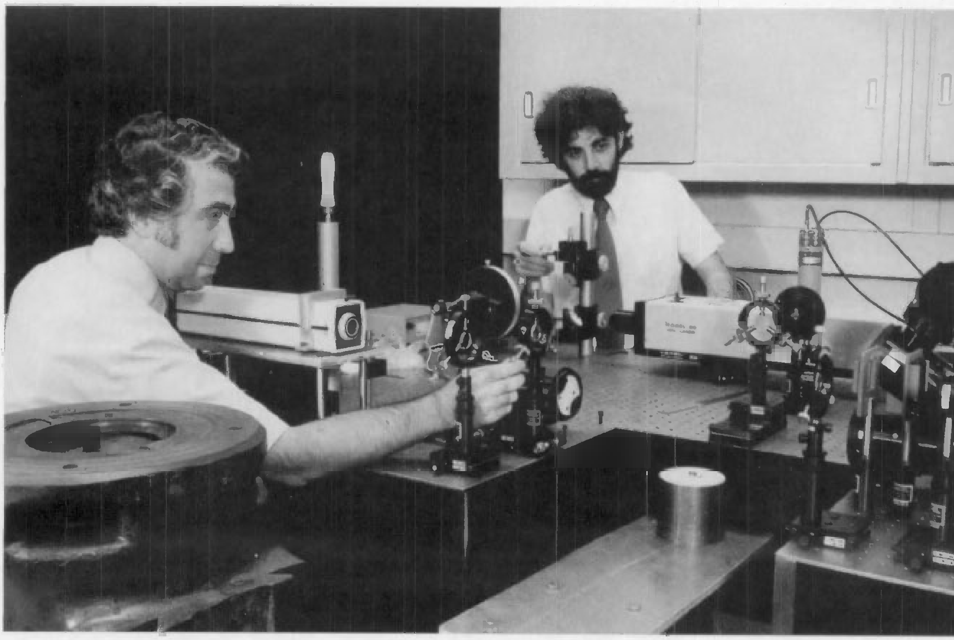
Computer Systems Laboratory

Much of the work of the Computer Systems Laboratory during this period was rooted in legislation—the *Brooks Act, Public Law 89-306*; the *Computer Security Act of 1987*, PL 100-235; and, of course, PL 100-418, the legislation that transformed NBS into NIST. The reach of the laboratory effort extended deep into America's computer-based technical structure, creating standards, guidelines, and test methods for computer systems and networks and providing assistance to both government and industrial information-system workers.

Under the leadership of director James H. Burrows, a hallmark of the laboratory was its role the development of the concept of "open systems," which allowed computer users to purchase and install computer equipment from a variety of sources without the fear of component incompatiblity that could hamper or entirely frustrate system efficiency. This role was buttressed by a program of research on computer security, software engineering, data management, and new types of systems. During Fiscal 1991, the laboratory enjoyed direct congressional funding of $12 million, augmented by $14 million in reimbursable funds—mostly from other Federal agencies.

[218] Thomas G. Cleary, Thomas J. Ohlemiller, and Kay M. Villa, "The influence of ignition source on the flaming fire hazard of upholstered furniture," *NISTIR 4847,* June 1992, 64 pp.

[219] T. G. Cleary, G. W. Mulholland, L. K. Ives, R. A. Fletcher, and J. W. Gentry, "Ultrafine combustion aerosol generator," *Aerosol Science and Technology* **16**, pp. 166-170 (1992).



Hratch G. Semerjian (left) and Robert J. Santoro developed a technique called optical tomography for taking cross-sectional "pictures" of mixed gas or liquid flow systems. The technique used an infrared laser and an array of optical detectors to determine the type and concentration of specific molecules in a given flow system.

Information Systems Engineering, David K. Jefferson, chief

The responsibilities of the Information Systems Engineering staff lay primarily in the areas of data administration, the technology of data management, testing of computer graphics, and the validation of software standards.

In 1989, Federal Information Processing Standard (FIPS) 156 was adopted. This standard was based on the Information Resource Dictionary System (IRDS), part of the standards library of the American National Standards Institute. Division personnel, led by Alan H. Goldfine, prepared test methods and techniques to evaluate use of the IRDS. Along with similar efforts in regard to the database language SQL, NIST rendered valuable assistance with the implementation of these information-management tools. Compliance with the requirements of FIPS 127—Database Language SQL—was eased by NIST's continuing development of test suites for SQL. During 1991 alone, 16 licenses were issued for use of the test suites.

FIPS 120, the Graphical Kernel System, required that implementations be tested prior to availability for Federal procurement. Some 9 copies of the *Programmer's Hierarchical Interactive Graphics System Validation Test Suite* were distributed by NIST during 1991, under the direction of Mark W. Skall.

The testing of programming language compilers for conformance to FIPS standards, too, continued to occupy division staff members. Several languages were included in the NIST work, among them COBOL, Fortran, Pascal, Ada, and MUMPS.

The ISE division played an important role in a Department of Defense program known as CALS—Computer-Aided Acquisition and Logistical Support. The program, begun in 1985, was intended to accelerate the development and deployment of both weapons systems and commercial products. In June 1991, Sharon J. Kemmerer provided a synopsis of NIST activities in support of the CALS program. These activities took place in several areas: electronic data interchange; graphics; document standards; raster compression; data management; security; and data communication. In each of the activity areas, Kemmerer noted the progress achieved during 1990. Many of the activities included contributions to military or civilian standards; others took the form of consultation and research work. Additionally, NIST served as a focal point for information receipt and distribution with regard to CALS.[220]

Systems and Software Technology, Allen L. Hankinson, chief, succeeded by Roger J. Martin, 1992

In April 1991, the SST division defined a framework for open systems in a broad range of Federal software systems applications—information technology services, protocols, interfaces, and data formats. The discussion was contained in *NIST Special Publication 500-187* entitled "Application Portability Profile (APP): The U.S. Government's Open Systems Environment Profile OSE/1 Version 1.0." Known as the APP Guide, the document rapidly gained wide acceptance in industrial information technology activities as well.

The division also supported the FIPS 151-1 POSIX protocol with conformance testing, facilitating the portability of applications software. Seven POSIX testing laboratories were accredited under the National Voluntary Laboratory Accreditation Program during 1991.

A third division initiative operated in the realm of open-systems standards for multimedia computer-based interactive training software. With the collaboration of other Federal agencies, NIST sought to create an environment in which such multimedia software would become available as commercial, off-the-shelf products.

Computer Security, Stuart W. Katzke, chief

A direct response to the Computer Security Act of 1987 could be seen in a joint NIST-National Security Agency project report published in September 1990. Instructed by the act to receive and review Federal security plans for unclassified but sensitive information, the two agencies immediately initiated the Computer Security and Privacy Plans (CSPP) review project. Dennis M. Gilbert coordinated the preparation of a report summarizing the results of the first year's work on the project.[221]

[220] Sharon J. Kemmerer, "NIST support of the CALS program; 1990 synopsis," *NISTIR 4609,* June 1991, 19 pp.

[221] Dennis M. Gilbert, "1989 Computer Security and Privacy Plans (CSPP) review project: a first-year Federal response to the Computer Security Act of 1987," *NISTIR 4409,* September 1990, 170 pp.

During the first year, the review team examined some 1500 plans from 63 civilian agencies and another 27,000 plans from over 400 Defense agencies. The team found considerable uncertainty among the agencies regarding the most effective means to provide for secure computer operations; thus, team recommendations focused on education. Each agency was urged to consider the types of loss that compromise of its system could entail, and to investigate the methods needed to prevent such loss. NIST plans for the second year included visits to the agencies by NIST, NSA, or Office of Management and Budget staff members for on-the-spot guidance. NIST also planned to develop model standardized specifications and language for agency use in contracting for assistance from security specialists.

It was clear to review team members that Federal computer security would continue to present a hazard for some time to come.

In its efforts to provide guidance and support to Federal agencies and industry in computer security, the division proposed in August 1991 that a FIPS be issued on the subject of digital signature standards for use by Federal agencies. In the proposed standard, a digital signature algorithm would be based on a public key. The digital signature standard would use the public key to verify to a recipient the integrity of data and the identity of the data source.

A revision of FIPS 140 was initiated to help a great variety of organizations to use the latest equipment to establish the physical and logical security requirements for the design and manufacture of data encryption standard equipment. The new revision was expected to form a framework within which cryptographic standards would be incorporated into new products.

During this period, the Computer Systems Laboratory initiated a new series of publications on computer security. Each report became part of *NIST Special Publication 800.* First in the series was a retrospective bibliography describing computer security in the 1980s, compiled by Rein Turn and edited by Lawrence E. Bassham. It was followed by "Public-key cryptography," by James R. Nechvatal, and "Establishing a computer security incident response capability," by John P. Wack.

Special Publication 800-7, issued in July of 1994 by a research team including Robert H. Bagwill, John F. Barkley, Jr., Lisa J. Carnahan, Shu-Jen H. Chang, David R. Kuhn, Paul Markovitz, Anastase Nakassis, Karen J. Olsen, Michael L. Ransom, and John P. Wack, contained a discussion of computer security in open systems. The 280-page document described the Federal response to threats of disruption to the *Public Switched Network,* which provided telecommunications for national security and emergency preparedness. It offered answers to programmers in the network for the question "How do I build security into software based on open system platforms?" The POSIX open system environment was described, with its security interfaces and mechanisms; also the X Window system, a network-transparent graphical user interface system, and the database language SQL. In each case, security considerations were discussed. A long section in the publication described further procedures to be used in achieving a secure system.

NIST computer scientist Karen Olsen and computer specialist Robert Bagwill worked to improve standards for open systems environments to allow greater compatibility among software systems.

Systems and Network Architecture, Kevin L. Mills, chief

In the Systems and Network Architecture division, NIST researchers worked with industry and other government agencies in three primary areas. In one of these areas, a division group headed by Frances Nielsen helped to establish standards for exchanging information on network management, emphasizing solutions to problems of communication among heterogeneous management systems. Methods utilized for this purpose included definitions for protocols needed for the exchange of management information, assembling proper formats for information under exchange, and preparing protocols for the support of the management function.

As an example of information exchange, we note the work of Paul Markovitz in 1991 on behalf of the Internal Revenue Service. Markovitz discussed the principles of electronic data interchange (EDI) as it applied to invoices, purchase orders, and other business information exchanged between companies. Use of electronic means for such exchange provided a quicker and more accurate set of transactions between trading partners.

Markovitz pointed out that electronic messages in the EDI system were not intended for humans, but were to be interpreted by computers in terms of inventory updates, shipping orders, billing, and the like. Many standard formats for EDI were available at that time—the three most widely used were known as X12, EDIFACT, and UN/TDI. The X12 family of formats was approved by the American National Standards Institute. A message handling system (MHS) provided a necessary interconnecting protocol to permit X12 messages to be exchanged between companies with incompatible computer systems. The balance of the 34-page report published by Markovitz consisted of a discussion of the nature of the MHS system and EDI.[222]

In another area, a division group under the leadership of Michael L. Ransom promoted the standardization and commercialization of networking technology. Activities in this area included standardization of the techniques for distribution and management of encryption keys, the design of a new protocol useful in negotiation of security services, facilitating the convergence of network-addressing methods, and standardizing algorithms involved in multicast transport and routing.

Yet a third area of work, led by J. P. Favreau, had as its goal the advancement of tools for editing, compiling, and interpreting computer communications protocols in order to automate their execution.

Advanced Systems, Shukri A. Wakid, chief

Personnel of the Advanced Systems division worked in the areas of parallel processing, data storage, distributed systems, and automated recognition.

[222] Paul Markovitz, "Electronic data interchange in message handling systems," *NISTIR 4608*, June 1991, 34 pp.

A group of scientists in the Systems and Network Architecture Division developed Open Systems Interconnection standards to facilitate the integration of computer components built by different manufacturers into efficient systems. Standing, from left to right, were Michael Anzenberger, Michael Wallace, and group leader Jerry Mulvenna. Seated were Deborah Tang and Paul Markovitz.

A primary activity, headed by David Su, involved the *Integrated Services Digital Network*. ISDN standards under development combined voice, data, text, and image communications within a single network connection. NIST helped develop the measurement capabilities and testbed facilities needed for conformance testing for the standards, as well as performance measurement techniques. An example of this activity was an overview of ISDN conformance testing prepared by Leslie A. Collica, Kathleen M. Roberts, and David Su; in a few pages, they outlined the scope of ISDN conformance testing, they described several test suites for as many layers of ISDN, they noted guidelines for conformance testing, and they provided information on test suite selection.[223]

[223] Leslie A. Collica, Kathleen M. Roberts, and David Su, "Overview of Integrated Services Digital Network conformance testing," *NIST Special Publication 823-1*, March 1992, 11 pp.

A study performed by William E. Burr examined the potential for voice, video, and data networks based on the use of optical fibers. Optical fibers, with the capability of information transfer by light waves, offered an enormous bandwidth relative to copper lines, and thus the possibility of carrying a correspondingly larger volume of information. Burr noted that the lagging development of fast, low-cost switching for optical fiber transmission had delayed the full utilization of its potential benefits. Burr speculated on the architectures that might be used in future high-bandwidth integrated services networks for voice, video, and data applications, comparing them with then-current schemes.[224]

Another group, led by Gordon E. Lyon, looked to enhance the evaluation and use of the most modern computers by the Federal government. Their activities ranged from the characterization of new computer architectures to the identification of improved capability for the automatic processing of data, to the study of programming methods that promised standardization among different classes of computer architecture.

An example of the characterization of state-of-the-art computer analysis was a study published by Robert D. Snelick in 1991. Snelick wished to examine the ratio of time spent by parallel processors in communication to the time spent in actual calculation. He noted that loosely coupled multiprocessors synchronized their operations and shared data through the exchange of explicit messages; thus the speed of communication was crucial to optimizing the performance of such machines.

A process Snelick called time dilation allowed him to vary the ratio of communication time to computational time for hypercube applications. The time dilation technique offered better detail on these features than previous methods of system analysis. Snelick employed as a test program a ring-type benchmark, in which a synthetic ring was created with a number of logical nodes or processes. Each node originated a given number of messages and also processed all other messages passing through it. When a particular message reached its originating node, it was removed from the network. When all messages programmed into the ring were processed, the program was complete. Message reception was acknowledged within the ring to prevent buffer overflow.

Snelick also used a random communication model benchmark in his tests, as well as a mesh model. He analyzed the results of the tests, finding that the time dilation technique provided an accurate method for investigating the performance of loosely coupled machine applications and, ultimately, improving the capabilities of programmers to better utilize their computing equipment.[225]

Yet a third team worked in the area of optical disks. Under the direction of Dana S. Grubb, group personnel stayed abreast of developments in optical disks, preparing test methods for conformance to both national and international standards.

David S. Pallett headed a group that was involved in collecting speech-recognition databases for distribution to dozens of organizations interested in the use of speech to direct the operation of computers.

[224] William E. Burr, "Architectures for future multigigabit lightwave networks," *NISTIR 90-4240*, February 1990, 64 pp.

[225] Robert D. Snelick, "Performance evaluation of hypercube applications: using a global clock and time dilation," *NISTIR 4630*, July 1991, 21 pp.

Leader of the NIST Automated Recognition Group David S. Pallett (left) and computer scientist James Hieronymus discussed a computer program designed to recognize vowels in their phonetic context.

Image recognition, too, received the attention of the Advanced Systems division. Research led by Charles L. Wilson was directed to the development of methods for evaluating image quality, efficiency of data storage, and systems used in optical character recognition. Among the projects touched by the work were fingerprint recognition and automation of personnel form completion.

Computing and Applied Mathematics Laboratory

The Computing and Applied Mathematics Laboratory staff was composed primarily of mathematicians and statisticians. Formed decades earlier as the Applied Mathematics Division, whose staff gave much-appreciated assistance on the interpretation of scientific data to researchers and calibration personnel alike, the division built as well a program of independent research. By 1991, under the leadership of Francis E. Sullivan, former chair of the Mathematics Department at the Catholic University of America, the new CAML program included mathematics, statistics, scientific computing, graphics generation, data manipulation, and parallel processing. Following the 1993 departure from NIST of Sullivan to engage in supercomputer research, NIST Director John Lyons appointed Joan R. Rosenblatt, veteran of nearly 40 years at NBS/NIST, to become laboratory director.

Applied and Computational Mathematics, Paul T. Boggs, chief

Parallel computing received the attention of a group under the leadership of Isabel Beichl. Realizing that algorithms and computer codes developed for data processing on single machines provided little increase in efficiency when transferred to parallel computers, the group conducted research on algorithms specifically for use in parallel processing. Particular problems addressed in the work were computational geometry and random processes.[226]

Work in the solution of computational geometry problems using parallel processing was discussed by Beichl and Sullivan in a 1991 paper. The authors noted the relative speed of progress in the use of parallel processing to solve problems in which iteration was known to be convergent—not the case with computational geometry problems. They outlined a new algorithm for triangulation to exploit the use of Single Instruction Multiple Data Stream computers.

Other groups in the division attacked problems in analytical approximation, particularly in non-linear mechanics calculations; mathematical modeling; optimization and computational geometry; and accurate and robust software for scientific computing.

Statistical Engineering, Robert J. Lundegard, chief

The Statistical Engineering Division staff supported experimental design as it had for decades. The division also developed strategies for data acquisition, graphical and numerical analysis, modeling of results, and estimation of experimental uncertainties for scientific, technical, and calibration personnel of NIST and its industrial collaborators.

An example of the work of the division during this period was a discussion of an ancient topic made new by changing events in science—uncertainty and accuracy in physical measurements—by Harry H. Ku. Ku outlined the historical scientific use of the term "uncertainty" to include "random" and "systematic" components. Random components could be treated statistically, whereas systematic components influenced all measurements leading to the reported results. Experimenters typically estimated bounds for the magnitudes of systematic uncertainties, added them linearly, and reported them separately from random error estimates.

In 1978, the International Bureau of Weights and Measures (BIPM) issued questionnaires to the national laboratories, seeking information and opinions on the treatment of uncertainties. In 1981, the BIPM issued a set of five rules for the combination of experimental uncertainties. In these rules, new categories replaced "random" and "systematic":

- Two categories for the components of experimental uncertainty were to be identified as "A"—those that were evaluated by statistical means—and "B"—those evaluated by other means. Detailed reports of all measurements were to include a complete list of the components, specifying the method used for each quantity. It was stressed that the new categories did not necessarily correspond to "random" or "systematic" definitions.

[226] I. Beichl and F. Sullivan, "Parallelizing computational geometry: first steps," *Siam News* **24**, No. 6, pp. 14-16 (1991).

- Category A components were to be characterized by the estimated variances s_i^2, (or the estimated standard deviations s_i) and the number of degrees of freedom, ν_i.

- Category B components were to be characterized by quantities u_j^2, which might be considered as approximations to the corresponding variances.

- The combined uncertainty was to be characterized by the numerical value obtained by applying the usual method for the combination of variances, with the use of standard deviations.

- If, for particular applications, it was necessary to multiply the combined uncertainty by a factor to obtain an overall uncertainty, the multiplying factor had to be stated.

Ku gave his own view of the new rules, pronouncing them "liberal" in potentially underestimating the overall uncertainty of a given measurement because of the "root-sum-of-squares" treatment of the non-statistical uncertainty components; in comparison, the older uncertainty treatments were "conservative," potentially overestimating the overall uncertainty because of the linear treatment of systematic uncertainties.

Ku suggested that the best justification for the new method of calculating uncertaintites should be the uniformity that it would give to the treatment of data. He also suggested that the new treatment, minimizing the effect of non-statistical uncertainties, was a healthy change in international metrology, since it more clearly delineated differences in metrological results among the various laboratories that sought an accurate measure of a physical quantity. The older definition of uncertainty, he wrote, was more suited to industrial calibration laboratories, where elucidation of the reproducibility of a set of measurements, not its fundamental accuracy, was the goal.[227]

Scientific Computing Environments, Sally E. Howe, chief

Early in the period, Darcy P. Barnett and David K. Kahaner described a computer program designed to solve ordinary differential equations, a common problem for scientists. The two called their program PLOD; it attempted to simulate human reasoning in the solution of such problems. [228]

One of the strong programs that developed in the Scientific Computing Environments division was the use of graphical display techniques for the presentation of results in physics and chemistry. Also under exploration was the manipulation of dynamic objects in scientific research and in automated design and manufacturing systems.

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[227] Harry H. Ku, "Uncertainty and accuracy in physical measurement," *NIST Special Publication 805,* December 1990, 9 pp.

[228] D. Barnett and D. Kahaner, "Experiences with an expert system for ODEs," *Mathematics and Computers in Simulation* 31, Nos. 4-5, pp. 315-323 (1989).

An interesting illustration of imaging techniques concerned the elucidation of the structure of "quasicrystals"—the icosahedral phase formed by rapid solidification of an aluminum-manganese alloy (see A "Renaissance" Scientist Comes to NBS in Ch. 4). At that time, no complete description of the atomic structure for the icosahedral phase had yet been found. In the investigation, division scientist Howland A. Fowler collaborated with A. J. Melmed—at that time in the private sector, but for many years a member of the NBS/NIST Surface Science Division—and H. B. Elswijk, a young scientist working for Philips Research Laboratories in Holland.

Starting with a field ion microscope image of the icosahedral phase showing two-fold, three-fold, and five-fold poles, the authors attempted to duplicate the experimental image by computer simulation. Beginning with the cubic phase, they gradually increased the size of the unit cell, introducing a manganese sublattice forming a collection of Mackay icosahedra decorated with aluminum atoms. As the unit cell size was increased from an edge length of 1.3 nm to 3.3 nm, the cubic features became weaker in comparison to pentagonal features. It was their view that the simulation experiment might point to an improved understanding of the interesting new structure.[229]

The division also carried the responsibility for maintaining the central NIST computing facility, as well as investigating the use of new computational hardware, software, and communications techniques.

The More Things Change, the More They Remain the Same: Industrial Productivity in Semiconductors—NIST Prefigured

In 1988, the National Bureau of Standards, an institution devoted to the creation of standards of measurement and to solving technical problems afflicting America, changed into the National Institute of Standards and Technology, an institution devoted to solving technical problems afflicting America and to the creation of standards of measurement. "A new institution, and not a better one, either," opined more than a few old-time employees. "A better institution, but hardly new," responded others.

One of the most cogent pieces of evidence indicating that only a change in emphasis—not a change in actual practices—occurred at NBS in 1988 could be found in a tale told later by an NBS/NIST senior manager who was on the scene for a long time. We are indebted to Judson C. French, who recently completed a half-century of service to NBS/NIST, for the details of a 1995 presentation to its Standards Alumni Association. His story, "Development of the NBS/NIST Semiconductor Program" is told from the point of view of a physicist who opened a long Bureau career with investigations of microwave gas tubes and semiconductor materials and devices shortly after World War II.[230]

[229] A. J. Melmed, H. B. Elswijk, and H. A. Fowler, "Field-ion microscope image simulations for icosahedral Al-Mn," *Colloque de Physique*, Supplement to Journal de Physique, 50, Colloque No. C8, November 1989, pp. C8-259 to C8-263.

[230] Judson C. French, "The NIST Electronics and Electrical Engineering Laboratory and the development of its semiconductor program," *NISTIR 6507* (2000).

The National Bureau of Standards had a difficult time keeping a scientific force to assist in the birth of transistorized electronics at mid-century. One effort, in the proximity fuze laboratory, was transferred to the U.S. Army along with the laboratory itself. A second effort began in 1955, when $30,000 of precious Bureau funds were apportioned to three sections in the Electricity Division—$10,000 each for work under Franklin Montgomery on transistor-based instrumentation, under Augustus Shapiro on transistor reliability, and under Charles Marsden on transistor physics. The transistor work was to be performed by French. The expertise developed in Montgomery's section disappeared when the general instrumentation project—of which it was a part—was disbanded. The reliability work left NBS with the rest of a U.S. Navy project of which it was a part.

French, working in the Bureau's Electron Tube Laboratory, digested William Shockley's first writings on transistors,[231] then began visits to Federal and industrial laboratories to find common needs in the transistor field. Soon, industry-wide problems surfaced in attempts to characterize semiconductor materials and devices. Such investigations suited NBS just fine, so French and his early colleagues William Keery and Marvin Phillips concentrated their efforts in those areas.

Visits to the American Society for Testing and Materials and to the Electronic Industries Association were similarly rewarding; both organizations were well aware of member complaints on the unreliability of semiconductor measurements.[232] From the plethora of problems, the NBS group selected semiconductor resistivity and second breakdown in transistors. Each was addressed successfully at NBS and the results were well-received by the growing semiconductor industry.

In the case of the resistivity of silicon—the most basic of measurements for electron device design and manufacture—measurement discrepancies were entirely too large to permit effective control of manufacturing processes or materials purchases. Rejecting the destructive two-probe measurement technique then believed by the industry to be necessary for accurate results, the NBS team, after visits with colleagues in industrial laboratories, developed a non-destructive, four-lead test involving commercially available instrumentation and precise procedures. The principal scientist in this project was Lydon J. Swartzendruber. The new techniques reduced measurement imprecision by more than a factor of ten.

French and his team took their new ideas to the ASTM for study by the semiconductor industry. Once the Bureau scientists convinced their industrial colleagues, through interlaboratory trials under ASTM oversight, that reproducible results could be

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[231] William Shockley, *Holes and electrons: an introduction to the physics of transistors* (Murray Hill, NJ: Bell Telephone Laboratories, 1949), based on lectures at the Bell Laboratories. See also William Shockley, *Electrons and holes in semiconductors, with applications to transistor electronics* (New York: Van Nostrand, 1950).

[232] Memorandum, J. C. French to R. D. Huntoon, Deputy Director NBS, March 9, 1960: "Minutes of a meeting of representatives of the Joint Electron Device Engineering Council and NBS on October 1, 1959.
See also
Letter, R. D. Huntoon to Virgil Graham, Chairman, Joint Electron Device Engineering Council and Associate director, EIA Engineering Department, June 1, 1960.

achieved only by the introduction of improved temperature control, more careful measurements, and better procedures, the NBS methods were quickly accepted.

Five industrial semiconductor measurement standards on silicon resistivity resulted from the NBS work, as well as several Standard Reference Materials.

In this one project undertaken in the mid-1950s, the NBS research team demonstrated the kind of close interaction with industry that Congress mandated in its 1988 Trade Act legislation—to select projects with high industry priority and a good match to the NBS measurement standards mission, and to involve industry directly in making quick use of the newly developed technology. Then, as later, NBS scientists found easy access to industrial laboratories because of their unique positions as objective scientific collaborators.

With the advice and assistance of the semiconductor industry, the NBS team conducted a benefit-cost study on the resistivity project.[233] The study showed economic benefits of more than $30 million in marketplace transactions as a result of the work—more than 100 times the cost of the project—and even more savings in manufacturing costs.

Although considerable time has passed since they were first developed, semiconductor resistivity SRMs recently were purchased from NIST by as many as 180 companies. A vice president of a process control systems firm stated, "the availability of resistivity SRMs was a significant factor in successfully developing and selling the $50 million installed base of these systems."[234]

Clearly, the NBS semiconductor research prefigured the later insistence that Bureau programs should be guided by industry needs.

In the second-breakdown project, for which Harry Schafft was the principal investigator, an even more startling development took place. During a visit to NBS by William Shockley, co-inventor of the transistor, the Bureau group reported to him experimental results that contradicted his theory of second breakdown. Convinced by the thoroughness of the NBS investigation, Shockley modified his theory to take account of the new results. The NBS characterization principles became widely applied in the industry.

As the NBS work in semiconductors became better known, more frequent requests for assistance were heard from industry and government alike. Under French's direction, NBS developed a joint program with funding and participation from other Federal agencies, attacking problems considered important by both industry and the agencies. Quarterly progress reports from the joint semiconductor project were requested by as many as 2000 representatives of organizations in industry, government, and academia.

[233] Judson C. French, "Improvement in the precision of measurement of electrical resistivity of single crystal silicon: a benefit-cost analysis," *NBS Electron Devices Section Internal Report 807*, September 20, 1967.

[234] Letter, Winthrop A. Baylies, President, The Baytech Group, to James Ehrstein, NBS, June 22, 1989. See also Letter, Winthrop A Baylies, Vice President/Marketing, ADE Corporation, to Malcolm Baldrige, Secretary of Commerce, November 25, 1981.

Passage of the Mansfield Act in 1973 seemed to doom the joint-agency program—no Department of Defense agency would be allowed to fund generic technologies. In the nick of time, however, the DoD Advanced Research Projects Agency commissioned NBS to undertake a multi-year, multi-million-dollar project to improve the performance and reliability of integrated circuits. Selection of NBS for the project was a direct result of the reputation for effective service gained by Bureau researchers.

The ARPA project accomplished more than the salvation of the NBS semiconductor research program; it also initiated a pattern of external contracting by NBS—using Bureau funds to pay for research to be done at universities and private companies. W. Murray Bullis, Alvin H. Sher, and Joseph A. Coleman led the NBS contract-monitor group.

The experience of the NBS contract monitors—who found that painstaking analysis and measurements were not part of the technical culture everywhere, and that the process of effectively monitoring technical aspects of contract research was both laborious and time-consuming—was not an entirely happy experience for the Bureau scientists. Yet, during the 6-year life of the ARPA program, some 30 contracts were let, some 240 report documents were prepared, and some $11 million was spent productively.[235] Most pleasing was a letter of praise for the NBS work, sent to the Secretary of Commerce by the ARPA director.[236] The letter stated that the program had met its objectives, industry had benefitted directly, and dramatic improvements had been realized in the performance and reliability of devices built for DoD use, saving millions of dollars for Defense agencies. As a consequence, the director predicted that his agency and the military services would expand their programs of joint DoD-DoC projects.

One of the ARPA program projects involved wire bonds to semiconductors. Unpredictable wire bond failures had imperiled the reliability of certain weapons. George G. Harman led the Bureau research effort to ameliorate the problem, visiting industrial laboratories and factories where bonding work was performed and then commencing NBS laboratory work with the help of existing (commercial) bonding equipment used for the DoD devices. Quickly, Harman found unexpected sensitivity in the bonding equipment to temperature variations and to vibrations, even those of small amplitude.

Harman's work led to better understanding of the physics of bonding, to new bonding procedures, and to improved equipment. Productivity in bonded circuit manufacture improved by as much as 35 times, and the improved quality permitted the use of circuit elements with as many as 500 bonds each. Failure of bonds in field systems ceased to be observed. Once again, NBS had anticipated the change to NIST.

[235] W. M. Bullis, "Advancement of reliability, processing, and automation for integrated circuits with the National Bureau of Standards (ARPA/IC/NBS)," *NBSIR 81-2224*, March 1981.

[236] Letter, Robert R. Fossum, Director, Advanced Research Projects Agency, to Juanita M. Kreps, Secretary of Commerce, April 17, 1979.

As the ARPA program drew to a close, NBS commissioned an "impact study" by the Charles River Associates to assess the value of the Bureau work to the semiconductor industry.[237] Industry officials were happy to testify to the importance of the NBS effort. Specific benefits cited included improved product reliability, improved production, lower costs, increased ability to meet customer specifications—even new directions for company research.

The Federal Government's financial stringency in the period almost caused the demise of the semiconductor project at the conclusion of the ARPA program, although new funds for the program had been appropriated by Congress. These would have replaced the ARPA support, but they were to be cut by the Office of Management and Budget. However, the perceived benefits of the program led to a successful industry-wide effort to make clear how important and appropriate it was for NBS to conduct such collaborative work with its own resources serving as a strong basis.[238] The program was saved and has continued to this day.

The semiconductor program provided direct benefits to industry through a continuous process of reaching outside of NBS for program guidance and evaluation. In that process it paralleled other programs described in this chapter—programs motivated to emphasize industrial productivity largely by the language of the 1988 Trade Act. The semiconductor program was not alone among NBS disciplines in initiating its policy of outreach decades prior to passage of the Trade Act—the fire research, building research, cryogenic engineering, time and frequency, and electromagentics programs, in particular, spring to mind immediately. But French's semiconductor progam serves admirably to demonstrate that no new practice for NBS as an institution was created when it became NIST in 1988. Rather, a culture already present in the agency was prescribed for its entire structure; a culture which believed that NIST should provide direct practical assistance to industry where NBS was uniquely positioned to respond, with that assistance backed up by the fundamental research needed to provide a solid foundation.

As NIST settles into its expanded role in the Nation's technical life, it remains to be seen whether the agency will retain the capability for fundamental work in physics and chemistry that characterized its first century of existence—the capability that made it instantly successful in its new role.

[237] Planning Report No. 8, "Productivity impacts of NBS R&D: a case study of the semiconductor technology program," Summary Volume, prepared for Planning Office, NBS; CRA Report No. 493, Charles River Associates, Inc., June 1981.

[238] Letter, T. D. Hinkelman, Executive Director, Semiconductor Industry Association, to David Stockman, Director, Office of Management and Budget, December 14, 1981.

APPENDIX A

LEGISLATION RELATING TO THE ORGANIZATION, FUNCTIONS, AND ACTIVITIES OF THE NATIONAL BUREAU OF STANDARDS/ NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

For most of the legislative acts, only those portions are reproduced that mandated action by NBS/NIST.

July 12, 1894, 28 Stat. 101 (Public Law 105—53d Congress, 2d session)

CHAP. 131.—An Act To define and establish the units of electrical measure.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That from and after the passage of this Act the legal units of electrical measure in the united States shall be as follows:

First. The unit of resistance shall be what is known as the international ohm, which is substantially equal to one thousand million units of resistance of the centimeter-gram-second system of electro-magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice fourteen and four thousand five hundred and twenty-one ten-thousandths grams in mass, of a constant cross-sectional area, and of the length of one hundred and six and three-tenths centimeters.

Second. The unit of current shall be what is known as the international ampere, which is one-tenth of the unit of current of the centimeter-gram-second system of electro-magnetic units, and is the practical equivalent of the unvarying current, which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of one thousand one hundred and eighteen millionths of a gram per second.

Third. The unit of electro-motive force shall be what is known as the international volt, which is the electro-motive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of an international ampere, and is practically equivalent to one thousand fourteen hundred and thirty-fourths of the electro-motive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of fifteen degrees centigrade, and prepared in the manner described in the standard specification.

Fourth. The unit of quantity shall be what is known as the international coulomb, which is the quantity of electricity transferred by a current of one international ampere in one second.

Fifth. The unit of capacity shall be what is known as the international farad, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.

Sixth. The unit of work shall be the Joule, which is equal to ten million units of work in the centimeter-gram-second system, and which is practically equivalent to the energy expended in one second by an international ampere in an international ohm.

Seventh. The unit of power shall be the Watt, which is equal to ten million units of power in the centimeter-gram-second system, and which is practically equivalent to the work done at the rate of one Joule per second.

Eighth. The unit of induction shall be the Henry, which is the induction in a circuit when the electromotive force induced in this circuit is one international volt while the inducing current varies at the rate of one Ampere per second.

SEC. 2. That it shall be the duty of the National Academy of Sciences to prescribe and publish, as soon as possible after the passage of this Act, such specifications of details as shall be necessary for the practical application of the definitions of the ampere and volt hereinbefore given, and such specifications shall be the standard specifications herein mentioned.

Approved, July 12, 1894.

* * * * *

March 3, 1901, 31 Stat. 1449 (Public Law 177—56th Congress, 2d session)
The first organic act for the National Bureau of Standards.

CHAP. 872.—An Act To establish the National Bureau of Standards.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Office of Standard Weights and Measures shall hereafter be known as the National Bureau of Standards.

SEC. 2. That the functions of the bureau shall consist in the custody of the standards; the comparison of the standards used in scientific investigations, engineering, manufacturing, commerce, and educational institutions with the standards adopted or recognized by the Government; the construction, when necessary, of standards, their multiples and subdivisions; the testing and calibration of standard measuring apparatus; the solution of problems which arise in connection with standards; the determination of physical constants and the properties of materials, when such data are of great importance to scientific or manufacturing interests and are not to be obtained of sufficient accuracy elsewhere.

SEC. 3. That the bureau shall exercise its functions for the Government of the United States; for any State or municipal government within the United States; or for any scientific society, educational institution, firm, corporation, or individual within the United States engaged in manufacturing or other pursuits requiring the use of standards or standard measuring instruments. All requests for the services of the bureau shall be made in accordance with the rules and regulations herein established.

SEC. 4. That the officers and employees of the bureau shall consist of a director, at an annual salary of five thousand dollars; one physicist, at an annual salary of three thousand five hundred dollars; one chemist, at an annual salary of three thousand five hundred dollars; two assistant physicists or chemists, each at an annual salary of two thousand two hundred dollars; one laboratory assistant, at an annual salary of one thousand four hundred dollars; one laboratory assistant, at an annual salary of one thousand two hundred dollars; one secretary, at an annual salary of two thousand dollars; one clerk, at an annual salary of one thousand two hundred dollars; one messenger, at an annual salary of seven hundred and twenty dollars; one engineer, at an annual salary of one thousand five hundred dollars; one mechanician, at an annual salary of one thousand four hundred dollars; one watchman, at an annual salary of seven hundred and twenty dollars, and one laborer, at an annual salary of six hundred dollars.

SEC. 5. That the director shall be appointed by the President, by and with the advice and consent of the Senate. He shall have the general supervision of the bureau, its equipment, and the exercise of its functions. He shall make an annual report to the Secretary of the Treasury, including an abstract of the work done during the year and a financial statement. He may issue, when necessary, bulletins for public distribution, containing such information as may be of value to the public or facilitate the bureau in the exercise of its functions.

SEC. 6. That the officers and employees provided for by this Act, except the director, shall be appointed by the Secretary of the Treasury, at such time as their respective services may become necessary.

SEC. 7. That the following sums of money are hereby appropriated: For the payment of salaries provided for by the Act, the sum of twenty-seven thousand one hundred and forty dollars, or so much thereof as may be necessary; toward the erection of a suitable laboratory, of fireproof construction, for the use and occupation of said bureau, including all permanent fixtures, such as plumbing, piping, wiring, heating, lighting, and ventilation, the entire cost of which shall not exceed the sum of two hundred and fifty thousand dollars, one hundred thousand dollars; for equipment of said laboratory, the sum of ten thousand dollars; for a site for said laboratory, to be approved by the visiting committee hereinafter provided for and purchased by the Secretary of the Treasury, the sum of twenty-five thousand dollars, or so much thereof as may be necessary; for the payment of the general expenses of said bureau, including books and periodicals, furniture, office expenses, stationery and printing, heating and lighting, expenses of the visiting committee, and contingencies of all kinds, the sum of five thousand dollars, or so much thereof as may be necessary, to be expended under the supervision of the Secretary of the Treasury.

SEC. 8. That for all comparisons, calibrations, tests, or investigations, except those performed for the Government of the United States or State governments within the United States, a reasonable fee shall be charged, according to a schedule submitted by the director and approved by the Secretary of the Treasury.

SEC. 9. That the Secretary of the Treasury shall, from time to time, make regulations regarding the payment of fees, the limits of tolerance to be attained in standards submitted for verification, the sealing of standards, the disbursement and receipt of moneys, and such other matters as he may deem necessary for carrying this Act into effect.

SEC. 10. That there shall be a visiting committee of five members, to be appointed by the Secretary of the Treasury, to consist of men prominent in the various interests involved, and not in the employ of the Government. This committee shall visit the bureau at least once a year, and report to the Secretary of the Treasury upon the efficiency of its scientific work and the condition of its equipment. The members of this committee shall serve without compensation, but shall be paid the actual expenses incurred in attending its meetings. The period of service of the members of the original committee shall be so arranged that one member shall retire each year, and the appointments thereafter to be for a period of five years. Appointments made to fill vacancies occurring other than in the regular manner are to be made for the remainder of the period in which the vacancy exists.

Approved, March 3, 1901.

* * * * *

May 20, 1918, 40 Stat 556 (Public Law 152—65th Congress, 2d session) "Overman Act."

First official interagency transfer of funds to the Bureau of Standards. The work was done in support of military agencies during World War I.

CHAP. 78.—An Act Authorizing the President to coordinate or consolidate executive bureaus, agencies, and offices, and for other purposes, in the interest of economy and the more efficient concentration of the Government.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That for the national security and defense, for the successful prosecution of the war, for the support and maintenance of the Army and Navy, for the better utilization of resources and industries, and for the more effective exercise and more efficient administration by the President of his powers as Commander in Chief of the land and naval forces the President is hereby authorized to make such redistribution of functions among executive agencies as he may deem necessary, including any functions, duties, and powers hitherto by law conferred upon any executive department, commission, bureau, agency, office, or officer, in such manner as in his judgment shall seem best fitted to carry out the purposes of this Act, and to this end is authorized to make such regulations and to issue such orders as he may deem necessary, which regulations and orders shall be in writing and shall be filed with the head of the department affected and constitute a public record: *Provided,* That the Act shall remain in force during the continuance of the present war and for six months after the termination of the war by the proclamation of the treaty of peace, or at such earlier time as the President may designate: *Provided further,* That the termination of this Act shall not affect any act done or any right or obligation accruing or accrued pursuant to the Act and during the time that this Act is in force: *Provided further,* That the authority by this Act granted shall be exercised only in matters relating to the conduct of the present war.

SEC. 2. That in carrying out the purposes of this Act the President is authorized to utilize, coordinate, or consolidate any executive or administrative commissions, bureaus, agencies, offices, or officers now existing by law, to transfer any duties or powers from one existing department, commission, bureau, agency, office, or officer to another, to transfer the personnel thereof or any part of it either by detail or assignment, together with the whole or any part of the records and public property belonging thereto.

* * * * *

May 29, 1920, 41 Stat 681 (Public Law 231—66th Congress, 2d session)
Beginning of transferred funds to the Bureau of Standards as authorized in appropriations legislation.

CHAP. 214.—An Act Making appropriations for the legislative, executive, and judicial expenses of the Government for the fiscal year ending June 30, 1921, and for other purposes.

During the fiscal year 1921, the head of any department or independent establishment of the Government having funds available for scientific investigations and requiring cooperative work by the Bureau of Standards on scientific investigations within the scope of the functions of that Bureau, and which it is unable to perform within the limits of its appropriations, may, with the approval of the Secretary of Commerce, transfer to the Bureau of Standards such sums as may be necessary to carry on such investigations. The Secretary of the Treasury shall transfer on the books of the Treasury Department any sums which may be authorized hereunder and such amounts shall be placed to the credit of the Bureau of Standards for the performance of work for the department or establishment from which the transfer is made. (41 Stat. 683)

* * * * *

May 14, 1930, 46 Stat. 327 (Public Law 219—71st Congress, 2d session)

CHAP. 275.—An Act Authorizing the establishment of a national hydraulic laboratory in the Bureau of Standards of the Department of Commerce and the construction of a building therefor.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That there is hereby authorized to be established in the Bureau of Standards of the Department of Commerce a national hydraulic laboratory for the determination of fundamental data useful in hydraulic research and engineering, including laboratory research relating to the behavior and control of river and harbor waters, the study of hydraulic structures and water flow, and the development and testing of hydraulic instruments and accessories: *Provided,* That no test, study, or other work on a problem or problems connected with a project the prosecution of which is under the jurisdiction of any department or independent agency of the government shall be undertaken in the laboratory herein authorized until a written request to do such work is submitted to the Director of the Bureau of Standards by the head of the department or independent agency charged with the execution of such project: *And provided further,* That any State or political subdivision thereof may obtain a test, study, or other work on a problem connected with a project the prosecution of which is under the jurisdiction of such State or political subdivision thereof.

SEC. 2. There is hereby authorized to be appropriated, out of any money in the Treasury not otherwise appropriated, not to exceed $350,000, to be expended by the Secretary of Commerce for the construction and installation upon the present site of the Bureau of Standards in the District of Columbia of a suitable hydraulic laboratory building and such equipment, utilities, and appurtenances thereto as may be necessary.

Approved, May 14, 1930.

* * * * *

June 30, 1932, 47 Stat. 382 (Public Law 212—72d Congress, 1st session) "Economy Act of 1932."

SEC. 312—An amendment to section 8 of the Act establishing the National Bureau of Standards authorized payment of fees, except for other Federal agencies, for Bureau of Standards tests and calibrations.

SEC. 601—The policy of transferred funds was restated and made general throughout the Federal Government.

[CHAPTER 314]

AN ACT

Making appropriations for the Legislative Branch of the Government for the fiscal year ending June 30, 1933, and for other purposes.

SEC. 312. Section 8 of the Act entitled "An Act to establish the National Bureau of Standards", approved March 3, 1901, as amended and supplemented [U.S.C., title 15, sec. 276], is amended to read as follows:

"SEC. 8. For all comparisons, calibrations, tests, or investigations, performed by the National Bureau of Standards under the provisions of this Act, as amended and supplemented, except those performed for the Government of the United States or State governments within the United States, a fee sufficient in each case to compensate the National Bureau of Standards for the entire cost of the services rendered shall be charged, according to a schedule prepared by the Director of the National Bureau of Standards and approved by the Secretary of Commerce. All moneys received from such sources shall be paid into the Treasury to the credit of miscellaneous receipts." (47 Stat. 410)

. . . .

SEC. 601. Section 7 of the Act entitled "An Act making appropriations for fortifications and other works of defense, for the armament thereof, and for the procurement of heavy ordnance for trial and service, for the fiscal year ending June 30, 1921, and for other purposes", approved May 21, 1920 [U.S.C., title 31, sec. 686], is amended to read as follows:

"SEC. 7. (a) Any executive department or independent establishment of the Government, or any bureau or office thereof, if funds are available therefor and if it is determined by the head of such executive department, establishment, bureau, or office to be in the interest of the Government so to do, may place orders with any other such department, establishment, bureau, or office for materials, supplies, equipment, work, or services of any kind that such requisitioned Federal agency may be in a position to supply or equipped to render, and shall pay promptly by check to such Federal agency as may be requisitioned, upon its written request, either in advance or upon the furnishing or performance thereof, all or part of the estimated or actual cost thereof, as determined by such department, establishment, bureau, or office as may be requisitioned; but proper adjustments on the basis of the actual cost of the materials, supplies, or equipment furnished, or work or services performed, paid for in advance, shall be made as may be agreed upon by the departments, establishments, bureaus, or offices concerned: *Provided, however,* That if such work or services can be as conveniently or more cheaply performed by private agencies such work shall be let by competitive bids to such private agencies. Bills rendered, or requests for advance payments made, pursuant to any such order, shall not be subject to audit or certification in advance of payment. (47 Stat. 417)

* * * * *

August 1, 1947, 61 Stat. 715 (Public Law 313—80th Congress, 1st session)

From time to time amendments to this act extended the authority to other agencies, revised the number of positions allotted, and the salary range. In 1965, NBS had twelve appointees under this law.

[CHAPTER 433]

AN ACT

To authorize the creation of additional positions in the professional and scientific service in the War and Navy Departments.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of War is authorized to establish and fix the compensation for, within the War Department, not more than thirty positions, and the Secretary of the Navy is authorized to establish and fix the compensation for, within the Naval establishment, not more than fifteen positions in the professional and scientific service, each such position being established to effectuate those research and development functions, relating to the national defense, military and naval medicine, and any and all other activities of the War Department or Naval Establishment which require the services of specially qualified scientific or professional personnel: *Provided,* That the rates of compensation for positions established pursuant to the provisions of this Act shall not be less than $10,000 per annum nor more than $15,000 per annum, and shall be subject to the approval of the Civil Service Commission.

SEC. 2. Positions created pursuant to this Act shall be included in the classified civil service of the United States, but appointments to such positions shall be made without competitive examination upon approval of the proposed appointee's qualifications by the Civil Service Commission or such officers or agents as it may designate for this purpose.

* * * * *

October 15, 1949, 63 Stat. 886 (Public Law 366—81st Congress, 1st session)
Authorization for the Boulder Laboratories.

[CHAPTER 703]

AN ACT

To authorize the construction and equipment of a radio laboratory building for the National Bureau of Standards, Department of Commerce.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That there is hereby authorized to be constructed and equipped for the National Bureau of Standards a suitable radio laboratory building, together with necessary utilities and appurtenances thereto, under a limit of cost of $4,475,000: *Provided,* That such limit of cost may be exceeded or shall be reduced by an amount equal to the percentage increase or decrease, if any, in construction costs generally dating from March 1, 1948, as determined by the Federal works Administrator.

SEC. 2. The Secretary of Commerce is authorized to acquire, by purchase, condemnation, or otherwise (including transfer with or without compensation from Federal agencies), such lands, estates in lands, and appurtenances thereto as may in his opinion be necessary or desirable for the construction of buildings to house activities of the National Bureau of Standards: *Provided,* That the site therefor shall be selected after consultation with the Director of the National Bureau of Standards.

SEC. 3. There are hereby authorized to be appropriated to the Secretary of Commerce, out of any moneys in the Treasury not otherwise appropriated, such sums as may be necessary to carry out the provisions of this Act: *Provided,* That such sums so appropriated, except such part thereof as may be necessary for the incidental expenses of the Department of Commerce, shall be transferred to the Public Buildings Administration in the Federal works Agency.

Approved October 25, 1949.

* * * * *

October 25, 1949, 63 Stat. 905 (Public Law 386—81st Congress, 1st session)
Authorization for a guided-missile research laboratory ultimately located on the site of a former United States Naval Hospital at Corona, California.

[CHAPTER 728]

AN ACT

To authorize the construction and equipment of a guided-missile research laboratory building for the National Bureau of Standards, Department of Commerce.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That there is hereby authorized to be constructed and equipped for the National Bureau of Standards a research laboratory building, suitable for use as a guided-missile laboratory, together with necessary utilities and appurtenances thereto, under a limit of cost of $1,900,000: *Provided,* That such limit of cost may be exceeded or shall be reduced by an amount equal to the percentage increase or decrease, if any, in construction cost generally dating from June 1, 1948, as determined by the Federal Works Administrator: *Provided further,* That such limit of cost shall not be exceeded by more than 10 per centum.

SEC. 2. The Secretary of Commerce is authorized to acquire, by purchase, condemnation, or otherwise (including transfer with or without compensation from Federal agencies), such lands, estates in lands, and appurtenances thereto as may in his opinion be necessary or desirable for the construction of a building to house activities of such laboratory for the National Bureau of Standards: *Provided,* That the site therefor shall be selected after consultation with the Director of the National Bureau of Standards.

SEC. 3. There are hereby authorized to be appropriated to the Secretary of Commerce, out of any moneys in the Treasury not otherwise appropriated, such sums as may be necessary to carry out the provisions of this Act: *Provided,* That such sums so appropriated, except such part thereof as may be necessary for the incidental expenses of the Department of Commerce, shall be transferred to the Public Buildings Administration in the Federal Works Agency.

Approved October 25, 1949.

* * * * *

October 28, 1949, 63 Stat. 954 (Public Law 429—81st Congress, 1st session) *Classification Act of 1949.* The number of positions for the whole Civil Service in grades GS-16, GS-17, and GS-18 were specified. Periodic revisions in number and salary were made. In 1965, the National Bureau of Standards had 39 appointees in GS-16 and 29 in GS-17.

[CHAPTER 782]

AN ACT

To establish a standard schedule of rates of basic compensation for certain employees of the Federal Government; to provide an equitable system for fixing and adjusting the rates of basic compensation of individual employees; to repeal the Classification Act of 1923, as amended; and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Classification Act of 1949".

TITLE I—DECLARATION OF POLICY

SEC. 101. It is the purpose of this Act to provide a plan for classification of positions and for rates of basic compensation whereby—

(1) in determining the rate of basic compensation which an officer or employee shall receive, (A) the principle of equal pay for substantially equal work shall be followed, and (B) variations in rates of basic compensation paid to different officers and employees shall be in proportion to substantial differences in the difficulty, responsibility, and qualification requirements of the work performed and to the contributions of officers and employees to efficiency and economy in the service; and

(2) individual positions shall, in accordance with their duties, responsibilities, and qualification requirements, be so grouped and identified by classes and grades, as defined in section 301, and the various classes shall be so described in published standards, as provided for in title IV, that the resulting position-classification system can be used in all phases of personnel administration.

* * * * *

January 23, 1950, 3 C.F.R. 76 (1950).

EXECUTIVE ORDER 10096

PROVIDING FOR A UNIFORM PATENT POLICY FOR THE GOVERNMENT WITH RESPECT TO INVENTIONS MADE BY GOVERNMENT EMPLOYEES AND FOR THE ADMINISTRATION OF SUCH POLICY.

WHEREAS inventive advances in scientific and technological fields frequently result from governmental activities carried on by Government employees; and

WHEREAS the Government of the United States is expending large sums of money annually for the conduct of these activities; and

WHEREAS these advances constitute a vast national resource; and

WHEREAS it is fitting and proper that the inventive product of functions of the Government, carried out by Government employees, should be available to the Government in appropriate instances; and

WHEREAS the rights of Government employees in their inventions should be recognized in appropriate instances; and

WHEREAS the carrying out of the policy of this order requires appropriate administrative arrangements:

NOW, THEREFORE, by virtue of the authority vested in me by the Constitution and statutes, and as President of the United States and Commander in Chief of the Armed Forces of the United States, in the interest of the establishment and operation of a uniform patent policy for the Government with respect to inventions made by Government employees, it is hereby ordered as follows:

1. The following basic policy is established for all Government agencies with respect to inventions hereafter made by any Government employee:

(a) The Government shall obtain the entire right, title and interest in and to all inventions made by any Government employee (1) during working hours, or (2) with a contribution by the Government of facilities, equipment, materials, funds, or information, or of time or services of other Government employees on official duty, or (3) which bears a direct relation to or are made in consequence of the official duties of the inventor.

(b) In any case where the contribution of the Government, as measured by any one or more of the criteria set forth in paragraph (a) last above, to the invention is insufficient equitably to justify a requirement of assignment to the Government of the entire right, title and interest to such invention, or in any case where the Government has insufficient interest in an invention to obtain entire right, title and interest therein (although the Government could obtain same under paragraph (a) above), the Government agency concerned, subject to the approval of the Chairman of the Government Patents Board . . . shall leave title to such invention in the employee, subject, however, to the reservation to the Government of a non-exclusive, irrevocable, royalty-free license in the invention with power to grant licenses for all governmental purposes, such reservation, in the terms thereof, to appear, where practicable, in any patent, domestic or foreign, which may issue on such invention. . . .

* * * * *

March 13, 1950, effective May 24, 1950, 64 Stat. 1263 (Reorganization Plan No. 5 of 1950)
The functions of all the officers of the National Bureau of Standards were transferred to the Secretary of Commerce, with power vested in him to authorize their performance or the performance of any of his functions by any of the officers or employees of the National Bureau of Standards.

REORGANIZATION PLAN NO. 5 OF 1950

Prepared by the President and transmitted to the Senate and the House of Representatives in Congress assembled, March 13, 1950, pursuant to the provisions of the Reorganization Act of 1949, approved June 20, 1949.

DEPARTMENT OF COMMERCE

SECTION 1. *Transfer of functions to the Secretary.*—(a) Except as otherwise provided in subsection (b) of this section, there are hereby transferred to the Secretary of Commerce all functions of all other officers of the Department of Commerce and all functions of all agencies and employees of such Department. . . .

SEC. 2. *Performance of functions of Secretary.*—The Secretary of Commerce may from time to time make such provisions as he shall deem appropriate authorizing the performance by any other officer, or by any agency or employee, of the Department of Commerce of any function of the Secretary, including any function transferred to the Secretary, including any function transferred to the Secretary by the provisions of this reorganization plan. . . .

SEC. 4. *Incidental transfers.*—The Secretary of Commerce may from time to time effect such transfers with the Department of Commerce of any of the records, property, personnel, and unexpended balances (available or to be made available) of appropriations, allocations, and other funds of such Department as he may deem necessary in order to carry out the provisions of this reorganization plan.

* * * * *

June 29, 1950, 64 Stat. 275 (Public Law 583, 81st Congress, 2d session) *Deficiency Appropriation Act, 1950.*
Beginning of the Working Capital Fund for the National Bureau of Standards.

[CHAPTER 405]

AN ACT

Making appropriations to supply deficiencies in certain appropriations for the fiscal year ending June 30, 1950, and for other purposes.

NATIONAL BUREAU OF STANDARDS

WORKING CAPITAL FUND

For the establishment of a working capital fund, to be available without fiscal year limitation, for expenses necessary for the maintenance and operation of the National Bureau of Standards, including the furnishing of facilities and services to other Government agencies, not to exceed $3,000,000. Said fund shall be established as a special deposit account and shall be reimbursed from applicable appropriations of said Bureau for the work of said Bureau, and from funds of other Government agencies for facilities and services furnished to such agencies pursuant to law. Reimbursements so made shall include handling and related charges; reserves for depreciation of equipment and accrued leave; and building construction and alterations directly related to the work for which reimbursement is made. (64 Stat. 279)

* * * * *

July 21, 1950, 64 Stat. 369 (Public Law 617, 81st Congress, 2d session)

The basic definitions of the act of 1894 were kept but eliminated the alternative definitions specifying devices which were not correct, gave clear legal effect in the United States to a world-wide agreement on electrical units and standards which had been obtained by the National Bureau of Standards, and established in scientific terms definitions of the units of light which had never been specifically established by Federal statutes.

[CHAPTER 484]

AN ACT

To redefine the units and establish the standards of electrical and photometric measurements.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That from and after the date this Act is approved, the legal units of electrical and photometric measurement in the United States of America shall be those defined and established as provided in the following sections.

SEC. 2. The unit of electrical resistance shall be the ohm, which is equal to one thousand million units of resistance of the centimeter-gram-second system of electromagnetic units.

SEC. 3. The unit of electric current shall be the ampere, which is one-tenth of the unit of current of the centimeter-gram-second system of electromagnetic units.

SEC. 4. The unit of electromotive force and of electric potential shall be the volt, which is the electromotive force that, steadily applied to a conductor whose resistance is one ohm, will produce a current of one ampere.

SEC. 5. The unit of electric quantity shall be the coulomb, which is the quantity of electricity transferred by a current of one ampere in one second.

SEC. 6. The unit of electrical capacitance shall be the farad, which is the capacitance of a capacitor that is charged to a potential of one volt by one coulomb of electricity.

SEC. 7. The unit of electrical inductance shall be the henry, which is the inductance in a circuit such that an electromotive force of one volt is induced in the circuit by variation of an inducing current at the rate of one ampere per second.

SEC. 8. The unit of power shall be the watt, which is equal to ten million units of power in the centimeter-gram-second system, and which is the power required to cause an unvarying current of one ampere to flow between points differing in potential by one volt.

SEC. 9. The units of energy shall be (a) the joule, which is equivalent to the energy supplied by a power of one watt operating for one second, and (b) the kilowatt-hour, which is equivalent to the energy supplied by a power of one thousand watts operating for one hour.

SEC. 10. The unit of intensity of light shall be the candle, which is one-sixtieth of the intensity of one square centimeter of a perfect radiator, known as a "black body", when operated at the temperature of freezing platinum.

SEC. 11. The unit of flux of light shall be the lumen, which is the flux in a unit of solid angle from a source of which the intensity is one candle.

SEC. 12. It shall be the duty of the Secretary of Commerce to establish the values of the primary electric and photometric units in absolute measure, and the legal values for these units shall be those represented by, or derived from, national reference standards maintained by the Department of Commerce.

SEC. 13. The Act of July 12, 1894 (Public Law Numbered 105, Fifty-third Congress), entitled "An Act to define and establish the units of electrical measure", is hereby repealed.

Approved July 21, 1950.

* * * * *

July 22, 1950, 64 Stat. 371 (Public Law 619, 81 Congress, 2d session)

First major restatement of Bureau functions since 1901. The Act rewrote section 2 in its entirety and expanded its provisions to cover the standards and measurements functions and activities of the Department of Commerce.

[CHAPTER 486]

AN ACT

To amend section 2 of the Act of March 3, 1901 (31 Stat. 1449), to provide basic authority for the performance of certain functions and activities of the Department of Commerce, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That section 2 of the Act of March 3, 1901 (31 Stat. 1449), as amended, be, and the same hereby is, further amended so as to read in full as follows:

"SEC. 2. The Secretary of Commerce (hereinafter referred to as the 'Secretary') is authorized to undertake the following functions:

"(a) The custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurements consistent with those standards, including the comparison of standards used in scientific investigations, engineering, manufacturing, commerce, and educational institutions with the standards adopted or recognized by the Government.

"(b) The determination of physical constants and properties of materials when such data are of great importance to scientific or manufacturing interests and are not to be obtained of sufficient accuracy elsewhere.

"(c) The development of methods for testing materials, mechanisms, and structures, and the testing of materials, supplies, and equipment, including items purchased for use of Government departments and independent establishments.

"(d) Cooperation with other governmental agencies on scientific and technical problems.

"(e) Advisory service to Government agencies on scientific and technical problems.

"(f) Invention and development of devices to serve special needs of the Government.

"In carrying out the functions enumerated in the section, the Secretary is authorized to undertake the following activities and similar ones for which need may arise in the operations of Government agencies, scientific institutions, and industrial enterprises:

"(1) the construction of physical standards;

"(2) the testing, calibration, and certification of standards and standard measuring apparatus;

"(3) the study and improvement of instruments and methods of measurements;

"(4) the investigation and testing of railroad track scales, elevator scales, and other scales used in weighing commodities for interstate shipment;

"(5) cooperation with the States in securing uniformity in weights and measures laws and methods of inspection;

"(6) the preparation and distribution of standard samples such as those used in checking chemical analyses, temperature, color, viscosity, heat of combustion, and other basic properties of materials; also the preparation and sale or other distribution of standard instruments, apparatus and materials for calibration of measuring equipment;

"(7) the development of methods of chemical analysis and synthesis of materials, and the investigation of the properties of rare substances;

"(8) the study of methods of producing and of measuring high and low temperatures; and the behavior of materials at high and at low temperatures;

"(9) the investigation of radiation, radioactive substances, and X-rays, their uses, and means of protection of persons from their harmful effects;

"(10) the study of the atomic and molecular structure of the chemical elements, with particular reference to the characteristics of the spectra emitted, the use of spectral observations in determining chemical composition of materials, and the relation of molecular structure to the practical usefulness of materials;

"(11) the broadcasting of radio signals for standard frequency;

"(12) the investigation of the conditions which affect the transmission of radio waves from their source to a receiver;

"(13) the compilation and distribution of information on such transmission of radio waves as a basis for choice of frequencies to be used in radio operation;

"(14) the study of new technical processes and methods of fabrication of materials in which the Government has a special interest; also the study of methods of measurement and technical processes used in the manufacture of optical glass and pottery, brick, tile, terra cotta, and other clay products;

"(15) the determination of properties of building materials and structural element, and encouragement of their standardization and most effective use, including investigation of fire-resisting properties of building materials and conditions under which they may be most efficiently used, and the standardization of types of appliances for fire prevention;

"(16) metallurgical research, including study of alloy steels and light metal alloys; investigation of foundry practice, casting, rolling, and forging; prevention of corrosion of metals and alloys; behavior of bearing metals; and development of standards for metals and sands;

"(17) the operation of a laboratory of applied mathematics;

"(18) the prosecution of such research in engineering, mathematics, and the physical sciences as may be necessary to obtain basic data pertinent to the functions specified herein; and

"(19) the compilation and publication of general scientific and technical data resulting from the performance of the functions specified herein or from other sources when such data are of importance to scientific or manufacturing interests or to the general public, and are not available elsewhere, including demonstrations of the results of the Bureau's work by exhibits or otherwise as may be deemed most effective."

SEC. 2. The Act of March 3, 1901 (31 Stat. 1449), as amended, be, and the same hereby is, further amended by inserting at the end thereof the following sections:

"SEC. 11. For all services rendered for other Government agencies by the Secretary in the performance of functions specified herein, the Department of Commerce may be reimbursed in accordance with section 601 of the Economy Act of June 30, 1932.

"SEC. 12. In the absence of specific agreement to the contrary, equipment purchased by the Department of Commerce from transferred or advanced funds in order to carry out an investigation authorized herein for another Government agency shall become the property of the Department of Commerce for use in subsequent investigations.

"SEC. 13. (a) The Secretary of Commerce is authorized to accept and utilize gifts or bequests of real or personal property for the purpose of aiding and facilitating the work authorized herein.

"(b) For the purpose of Federal income, estate, and gift taxes, gifts and bequests accepted by the Secretary of Commerce under the authority of the Act shall be deemed to be gifts and bequests to or for the use of the United States."

Approved July 22, 1950

* * * * *

September 9, 1950, 64 Stat. 823 (Public Law 776—81st Congress, 2d session)

The Technical Documentation Center in the Department of Commerce was transferred to the National Bureau of Standards in 1964. Reorganized and renamed the Clearinghouse for Federal Scientific and Technical Information, it provided inexpensive unclassified information about government-sponsored research and development in national programs.

[CHAPTER 936]

AN ACT

To provide for the dissemination of technological, scientific, and engineering information to American business and industry, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the purpose of this Act is to make the results of technological research and development more readily available to industry and business, and to the general public, by clarifying and defining the functions and responsibilities of the Department of Commerce as a central clearinghouse for technical information which is useful to American industry and business.

CLEARINGHOUSE FOR TECHNICAL INFORMATION

SEC. 2. The Secretary of Commerce (hereinafter referred to as the "Secretary") is hereby directed to establish and maintain within the Department of Commerce a clearinghouse for the collection and dissemination of scientific, technical, and engineering information, and to this end to take such steps as he may deem necessary and desirable—

(a) To search for, collect, classify, coordinate, integrate, record, and catalog such information from whatever sources, foreign and domestic, that may be available;

(b) To make such information available to industry and business, to State and local governments, to other agencies of the Federal Government, and to the general public, through the preparation of abstracts, digests, translations, bibliographies, indexes, and microfilm and other reproductions, for distribution either directly or by utilization of business, trade, technical, and scientific publications and services;

(c) To effect, within the limits of his authority as now or hereafter defined by law, and with the consent of competent authority, the removal of restrictions on the dissemination of scientific and technical data in cases where consideration of national security permit the release of such data for the benefit of industry and business.

* * * * *

June 30, 1953, 67 Stat. 111 (Public Law 88—83d Congress, 1st session) *Flammable Fabrics Act.*
Mandatory flammability standards were set for wearing apparel and fabrics in interstate commerce. The standards relied on the voluntary commercial standards adopted by industry working with the National Bureau of Standards over several years to produce these standards for the industry.

Public Law 88 CHAPTER 164

AN ACT

To prohibit the introduction or movement in interstate commerce of articles of wearing apparel and fabrics which are so highly flammable as to be dangerous when worn by individuals, and for other purposes.

STANDARD OF FLAMMABILITY

SEC. 4. (a) Any fabric or article of wearing apparel shall be deemed so highly flammable within the meaning of section 3 of this Act as to be dangerous when worn by individuals if such fabric or any uncovered or exposed part of such article of wearing apparel exhibits rapid and intense burning when tested under the conditions and in the manner prescribed in the Commercial Standard promulgated by the Secretary of Commerce effective January 30, 1953, and identified as "Flammability of Clothing Textiles, Commercial Standard 191-53", or exhibits a rate of burning in excess of that specified in paragraph 3.11 of the Commercial Standard promulgated by the Secretary of Commerce effective May 22, 1953, and identified as "General Purpose Vinyl Plastic Film, Commercial Standard 192-53". For the purposes of this Act, such Commercial Standard 191-53 shall apply with respect to the hats, gloves, and footwear.

(b) If at any time the Secretary of Commerce finds that the Commercial Standards referred to in subsection (a) of this section are inadequate for the protection of the public interest, he shall submit to the Congress a report setting forth his findings together with such proposals for legislation as he deems appropriate. (67 Stat. 112)

* * * * *

June 20, 1956, 70 Stat. 314 (Public Law 604—84th Congress, 2d session)
Formal approval for the construction of new Bureau laboratories at Gaithersburg.

Public Law 604 CHAPTER 415

AN ACT

Making appropriations for the Department of Commerce and related agencies for the fiscal year ending June 30, 1957, and for other purposes.

Construction of facilities: For acquisition of necessary land and to initiate the design of the facilities to be constructed thereon for the National Bureau of Standards outside of the District of Columbia to remain available until expended, $930,000, to be transferred to the General Services Administration. (70 Stat. 321)

* * * * *

August 2, 1956, 70 Stat. 953 (Public Law 930—84th Congress, 2d session)

The Secretary of Commerce was directed to prescribe commercial standards for a safety device which would enable the refrigerator door to be opened from the inside. The National Bureau of Standards, with the cooperation of the refrigerator manufacturing industry, engaged in experiments to determine the basic criteria of reasonable safety which manufacturers could incorporate in the design of their refrigerators for preventing the suffocation of children entrapped in refrigerators.

Public Law 930 CHAPTER 890

AN ACT

To require certain safety devices on household refrigerators shipped in interstate commerce.

SEC. 3. The Secretary of Commerce shall prescribe and publish in the Federal Register commercial standards for devices which, when used in or on household refrigerators, will enable the doors thereof to be opened easily from the inside; and the standards first established under this section shall be so prescribed and published not later than one year after the date of the enactment of this Act.

* * * * *

August 3, 1956, 70 Stat. 959 (Public Law 940, 84th Congress, 2d session)

The Organic Act of the National Bureau of Standards was amended by Section 7 of this law which authorized the Bureau to retain fees received from the public for services performed, and allowed the Bureau to charge fixed prices for services performed for other agencies. Section 12 (a) incorporated authority for use of the Working Capital Fund in the Organic Act, and permitted changes in the accounting treatment under the fund.

Public Law 940

AN ACT

To amend the Act of March 3, 1901 (31 Stat. 1449) as amended, to incorporate in the Organic Act of the National Bureau of Standards the authority to use the Working Capital Fund, and to permit certain improvements in fiscal practices.

"SEC. 7. The Secretary shall charge for services performed under the authority of section 3 of this Act, except in cases where he determines that the interest of the Government would be best served by waiving the charge. Such charges may be based upon fixed prices or cost. The appropriation or fund bearing the cost of the services may be reimbursed, or the Secretary may require advance payment subject to such adjustment on completion of the work as may be agreed upon.

"SEC. 12. (a) The National Bureau of Standards is authorized to utilize in the performance of its functions the Working Capital Fund established by the Act of June 29, 1950 (64 Stat. 275), and additional amounts as from time to time may be required for the purposes of said fund are hereby authorized to be appropriated.

* * * * *

November 4, 1963, 77 Stat. 299 (Public Law 88-165, 88th Congress, 1st session)

Public Law 88-165

AN ACT

To amend the Act redefining the units and establishing the standards of electrical and photometric measurements to provide that the candela shall be the unit of luminous intensity.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Act entitled "An Act to redefine the units and establish the standards of electrical and photometric measurement" (Act of July 21, 1950; (64 Stat. 370) is amended by deleting the word "candle" wherever it appears and inserting in lieu thereof the word "candela".

Approved November 4, 1963.

* * * * *

October 30, 1965, 79 Stat. 1127 (Public Law 89-306—89th Congress, 1st session) "Brooks Act"

As the technical representative of the Department of Commerce, the National Bureau of Standards established the Center for Computer Sciences and Technology to improve the effectiveness and efficiency of the government's use of computers.

Public Law 89-306

AN ACT

To provide for the economic and efficient purchase, lease, maintenance, operation, and utilization of automatic data processing equipment by Federal departments and agencies.

"AUTOMATIC DATA PROCESSING EQUIPMENT

"(f) The Secretary of Commerce is authorized (1) to provide agencies, and the Administrator of General Services in the exercise of the authority delegated in this section, with scientific and technological advisory services relating to automatic data processing and related systems, and (2) to make appropriate recommendations to the President relating to the establishment of uniform Federal automatic data processing standards. The Secretary of Commerce is authorized to undertake the necessary research in the sciences and technologies of automatic data processing computer and related systems, as may be required under provisions of this subsection. (70 Stat. 1128)

* * * * *

September 9, 1966, 80 Stat. 718 (Public Law 89-563—89th Congress, 2d session) *National Traffic and Motor Vehicle Safety Act of 1966.*

The Secretary of Commerce was to use the facilities of the National Bureau of Standards to initiate and conduct research, testing, development, and evaluation in cooperation with other Federal departments and agencies. The brake fluid and seat belt legislation passed in 1962 and 1963 was repealed by this broader law.

Public Law 89-563

AN ACT

To provide for a coordinated national safety program and establishment of safety standards for motor vehicles in interstate commerce to reduce accidents involving motor vehicles and to reduce the death and injuries occurring in such accidents.

SEC. 103. (f) In prescribing standards under this section, the Secretary shall—

(1) consider relevant available motor vehicle safety data, including the results of research, development, testing and evaluation activities conducted pursuant to the Act; . . . (80 Stat. 719)

* * * * *

October 15, 1966, 80 Stat. 931 (Public Law 89-670—89th Congress, 2d session) *Department of Transportation Act.*

The functions, powers, and duties given to the Secretary of Commerce under the *National Traffic and Motor Vehicle Safety Act of 1966* were transferred to the Secretary of Transportation. The Office of Vehicle Systems Research was formed at the National Bureau of Standards in March 1967.

Public Law 89-670

AN ACT

To establish a Department of Transportation and for other purposes.

TRANSFERS TO DEPARTMENT

SEC. 6. (a) There are hereby transferred to and vested in the Secretary all functions, powers, and duties of the Secretary of Commerce and other offices and officers of the Department of Commerce under—

(6) the following laws relating generally to traffic and highway safety:

(A) The National Traffic and Motor Vehicle Safety Act of 1966 (80 Stat. 718).

(B) The Highway Safety Act of 1966 (80 Stat. 731).

* * * * *

November 3, 1966, 80 Stat. 1296 (Public Law 89-755—89th Congress, 2d session) *Fair Packaging and Labeling Act.*

The National Bureau of Standards was given the responsibility to work with industry to reduce the number of package sizes, and to make labels more informative.

Public Law 89-755

AN ACT

To regulate interstate and foreign commerce by preventing the use of unfair or deceptive methods of packaging or labeling of certain consumer commodities distributed in such commerce, and for other purposes.

SEC. 5. (d) Whenever the Secretary of Commerce determines that there is undue proliferation of the weights, measures, or quantities in which any consumer commodity or reasonably comparable consumer commodities are being distributed in packages for sale at retail and such undue proliferation impairs the reasonable ability of consumers to make value comparisons with respect to such consumer commodity or commodities, he shall request manufacturers, packers, and distributors of the commodity or commodities to participate in the development of a voluntary product standard for such commodity or commodities under the procedures for the development of voluntary products standards established by the Secretary pursuant to section 2 of the Act of March 3, 1901 (31 Stat. 1449, as amended; 15 U.S.C. 272). Such procedures shall provide adequate manufacturer, packer, distributor, and consumer representation.

(e) If (1) after one year after the date on which the Secretary of Commerce first makes the request of manufacturers, packers, and distributors to participate in the development of a voluntary product standard as provided in subsection (d) of this section, he determines that such a standard will not be published pursuant to the provisions of such subsection (d), or (2) if such a standard is published and the Secretary of Commerce determines that it has not been observed, he shall promptly report such determination to the Congress with a statement of the efforts that have been made under the voluntary standards program and his recommendation as to whether Congress should enact legislation providing regulatory authority to deal with the situation in question. (80 Stat. 1299)

. . . .

REPORTS TO THE CONGRESS

SEC. 8. Each officer or agency required or authorized by the Act to promulgate regulations for the packaging or labeling of any consumer commodity, or to participate in the development of voluntary product standards with respect to any consumer commodity under procedures referred to in section 5 (d) of this Act, shall transmit to the Congress in January of each year a report containing a full and complete description of the activities of that officer or agency for the administration and enforcement of this Act during the preceding fiscal year.

COOPERATION WITH STATE AUTHORITIES

SEC. 9. (a) A copy of each regulation promulgated under this Act shall be transmitted promptly to the Secretary of Commerce, who shall (1) transmit copies thereof to all appropriate State officers and agencies, and (2) furnish to such State officers and agencies information and assistance to promote to the greatest practicable extent uniformity in State and Federal regulation of the labeling of consumer commodities.

(b) Nothing contained in this section shall be construed to impair or otherwise interfere with any program carried into effect by the Secretary of Health, Education, and Welfare under other provisions of law in cooperation with State government or agencies, instrumentalities, or political subdivisions thereof. (80 Stat. 1300)

* * * * *

December 14, 1967, 81 Stat. 568 (Public Law 90-189—90th Congress, 1st session)

The Flammable Fabrics Act amendments provided a mechanism for continued evaluation and revision to keep the requirements up- to-date and extended coverage to flammable interior furnishings. The Secretary of Commerce was given the responsibility of developing mandatory flammability standards when necessary. NBS had the responsibility of providing the necessary technical information.

Public Law 90-189

AN ACT

To amend the Flammable Fabrics Act to increase the protection afforded consumers against injurious flammable fabrics.

SEC. 3. Section 4 of the Flammable Fabrics Act is amended to read as follows:

"REGULATION OF FLAMMABLE FABRICS

"SEC. 4. (a) Whenever the Secretary of Commerce finds on the basis of the investigations or research conducted pursuant to section 14 of this Act that a new or amended flammability standard or other regulation, including labeling, for a fabric, related material, or product may be needed to protect the public against unreasonable risk of the occurrence of fire leading to death or personal injury, or significant property damage, he shall institute proceedings for the determination of an appropriate flammability standard (including conditions and manner of testing) or other regulation or amendment thereto for such fabric, related material, or product.

"(b) Each standard, regulation, or amendment thereto promulgated pursuant to this section shall be based on findings that such standard, regulation, or amendment thereto is needed to adequately protect the public against unreasonable risk of the occurrence of fire leading to death, injury, or significant property damage, is reasonable, technologically practicable, and appropriate, is limited to such fabrics, related materials, or products which have been determined to present such unreasonable risks, and shall be stated in objective terms. Each such standard, regulation, or amendment thereto, shall become effective twelve months from the date on which such standard, regulation, or amendment is promulgated, unless the Secretary of Commerce finds for good cause shown that an earlier or later effective date is in the public interest and publishes the reason for such finding. Each such standard or regulation or amendment thereto shall exempt fabrics, related materials, or products in inventory or with the trade as of the date on which the standard, regulation, or amendment thereto, becomes effective except that, if the Secretary finds that any such fabric, related material, or product is so highly flammable as to be dangerous when used by consumers for the purpose for which it is intended, he may under such conditions as the Secretary may prescribe, withdraw, or limit the exemption for such fabric, related material, or product. (81 Stat. 569)

* * * * *

March 1, 1968, 82 Stat. 34 (Public Law 90-259—90th Congress, 2d session) *Fire Research and Safety Act of 1968.*

The Fire Research and Safety Office was created to carry out the activities of the program.

Public Law 90-259

AN ACT

To amend the Organic Act of the National Bureau of Standards to authorize a fire research and safety program, and for other purposes.

Title I—FIRE RESEARCH AND SAFETY PROGRAM

DECLARATION OF POLICY

SEC. 101. The Congress finds that a comprehensive fire research and safety program is needed in this country to provide more effective measures of protection against the hazards of death, injury, and damage to property. The Congress finds that it is desirable and necessary for the Federal Government, in carrying out the provisions of this title, to cooperate with and assist public and private agencies. The Congress declares that the purpose of this title is to amend the Act of March 3, 1901, as amended, to provide a national fire research and safety program including the gathering of comprehensive fire data; a comprehensive fire research program; fire safety education and training programs; and demonstrations of new approaches and improvements in fire prevention and control, and reduction of death, personal injury, and property damage. Additionally, it is the sense of Congress that the Secretary should establish a fire research and safety center for administering this title and carrying out its purposes, including appropriate fire safety liaison and coordination.

AUTHORIZATION OF PROGRAM

SEC. 102. The Act entitled "An Act to establish the National Bureau of Standards", approved March 3, 1901, as amended (15 U.S.C. 271-278e, is further amended by adding the following sections:

"SEC. 16. The Secretary of Commerce (hereinafter referred to as the 'Secretary') is authorized to—

"(a) Conduct directly or through contracts or grants—

"(1) investigations of fires to determine their causes, frequency of occurrence, severity, and other pertinent factors;

"(2) research into the causes and nature of fires, and the development of improved methods and techniques for fire prevention, fire control, and reduction of death, personal injury, and property damage;

"(3) educational programs to—

"(A) inform the public of fire hazards and fire safety techniques, and

"(B) encourage avoidance of such hazards and use of such techniques;

"(4) fire information reference services, including the collection, analysis, and dissemination of data, research results, and other information, derived from this program or from other sources and related to fire protection, fire control, and reduction of death, personal injury, and property damage;

"(5) educational and training programs to improve, among other things—

"(A) the efficiency, operation, and organization of fire services, and

"(B) the capability of controlling unusual fire-related hazards and fire disasters; and

"(6) projects demonstrating—

"(A) improved or experimental programs of fire prevention, fire control, and reduction of death, personal injury, and property damage,

"(B) application of fire safety principles in construction, or

"(C) improvement of the efficiency, operation, or organization of the fire services.

"(b) Support by contracts or grants the development, for use by educational and other nonprofit institutions, of—

"(1) fire safety and fire protection engineering or science curriculums; and

"(2) fire safety courses, seminars, or other instructional materials and aids for the above curriculums or other appropriate curriculums or courses of instruction.

"SEC. 17. With respect to the functions authorized by section 16 of this Act—

"(a) Grants may be made only to States and local governments, other non-Federal public agencies, and nonprofit institutions. Such a grant may be up to 100 per centum of the total cost of the project for which such grant is made. The Secretary shall require, whenever feasible, as a condition of approval of a grant, that the recipient contribute money, facilities, or services to carry out the purpose for which the grant is sought. For the purposes of this section, 'State' means any State of the United States, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, the Canal Zone, American Samoa, and the Trust Territory of the Pacific Islands; and 'public agencies' includes combinations or groups of States or local governments.

"(b) The Secretary may arrange with and reimburse the heads of other Federal departments and agencies for the performance of any such functions, and, as necessary or appropriate, delegate any of his powers under this section or section 16 of this Act with respect to any part thereof, and authorize the redelegation of such powers.

"(c) The Secretary may perform such functions without regard to section 3648 of the Revised Statutes (31 U.S.C. 529).

"(d) The Secretary is authorized to request any Federal department or agency to supply such statistics, data, program reports, and other materials as he deems necessary to carry out such functions. Each such department or agency is authorized to cooperate with the Secretary and, to the extent permitted by law, to furnish such materials to the Secretary. The Secretary and the heads of other departments and agencies engaged in administering programs related to fire safety shall, to the maximum extent practicable, cooperate and consult in order to insure fully coordinated efforts.

"(e) The Secretary is authorized to establish such policies, standards, criteria, and procedures and to prescribe such rules and regulations as he may deem necessary or appropriate to the administration of such functions or this section, including rules and regulations which—

"(1) provide that a grantee will from time to time, but not less often than annually, submit a report evaluating accomplishments of activities funded under section 16, and

"(2) provide for fiscal control, sound accounting procedures, and periodic reports to the Secretary regarding the application of funds paid under section 16."

* * * * *

July 11, 1968, 82 Stat. 339 (Public Law 90-396—90th Congress, 2d session) *Standard Reference Data Act.* This Act authorized the National Bureau of Standards to coordinate a National system for providing scientific data to science and industry, thereby strengthening and increasing the effectiveness of the Bureau's standard reference data operation.

Public Law 90-396

AN ACT

To provide for the collection, compilation, critical evaluation, publication, and sale of standard reference data.

DECLARATION OF POLICY

SECTION 1. The Congress hereby finds and declares that reliable standardized scientific and technical reference data are of vital importance to the progress of the Nation's science and technology. It is therefore the policy of the congress to make critically evaluated reference data readily available to scientists, engineers, and the general public. It is the purpose of this Act to strengthen and enhance this policy.

SEC. 2. For the purposes of this Act—

(a) The term "standard reference data" means quantitative information, related to a measurable physical or chemical property of a substance or system of substances of known composition and structure, which is critically evaluated as to its reliability under section 3 of this Act.

(b) The term "Secretary" means the Secretary of Commerce.

SEC. 3. The Secretary is authorized and directed to provide or arrange for the collection, compilation, critical evaluation, publication, and dissemination of standard reference data. In carrying out this program, the Secretary shall, to the maximum extent practicable, utilize the reference data services and facilities of other agencies and instrumentalities of the Federal Government and of State and local governments, persons, firms, institutions, and associations, with their consent and in such a manner as to avoid duplication of those services and facilities. All agencies and instrumentalities of the Federal Government are encouraged to exercise their duties and functions in such manner as will assist in carrying out the purpose of this Act. This section shall be deemed complementary to existing authority, and nothing herein is intended to repeal, supersede, or diminish existing authority or responsibility of any agency or instrumentality of the Federal Government.

SEC. 4. To provide for more effective integration and coordination of standard reference data activities, the Secretary, in consultation with other interested Federal agencies, shall prescribe and publish in the Federal Register such standards, criteria, and procedures for the preparation and publication of standard reference data as may be necessary to carry out the provisions of this Act.

SEC. 5. Standard reference data conforming to standards established by the Secretary may be made available and sold by the Secretary or by a person or agency designated by him. To the extent practicable and appropriate, the prices established for such data may reflect the cost of collection, compilation, evaluation, publication, and dissemination of the data, including administrative expenses; and the amounts received shall be subject to the Act of March 3, 1901, as amended (15 U.S.C. 271- 278e).

SEC. 6. (a) Notwithstanding the limitations contained in section 9 of title 17 of the United States Code, the Secretary may secure copyright and renewal thereof on behalf of the United States as author or proprietor in all or any part of any standard reference data which he prepares or makes available under this Act, and may authorize the reproduction and publication thereof by others.

(b) The publication or republication by the Government under this Act, either separately or in a public document, of any material in which copyright is subsisting shall not be taken to cause any abridgment or annulment of the copyright or to authorize any use or appropriation of such material without the consent of the copyright proprietor.

SEC. 7. There are authorized to be appropriated to carry out this Act, $1.86 million for the fiscal year ending June 30, 1969. Notwithstanding the provisions of any other law, no appropriations for any fiscal year may be made for the purpose of this Act after fiscal year 1969 unless previously authorized by the Congress.

SEC. 8. This Act may be cited as the "Standard Reference Data Act."

Approved July 11, 1968.

* * * * *

August 9, 1968, 82 Stat. 693 (Public Law 90-472—90th Congress, 2d session) "Metric System Study".
The Act authorized a study of the effect upon the United States of increased use of the Metric System throughout the world and development of recommendations for an action program to deal with the problem.

Public Law 90-472

AN ACT

To authorize the Secretary of Commerce to make a study to determine the advantages and disadvantages of increased use of the metric system in the United States.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of Commerce is hereby authorized to conduct a program of investigation, research, and survey to determine the impact of increasing worldwide use of the metric system on the United States; to appraise the desirability and practicability of increasing the use of metric weights and measures in the United States; to study the feasibility of retaining and promoting by international use of dimensional and other engineering standards based on the customary measurement units of the United States; and to evaluate the costs and benefits of alternative courses of action which may be feasible for the United States.

SEC. 2. In carrying out the program described in the first section of this Act, the Secretary, among other things, shall—

(1) investigate and appraise the advantages and disadvantages to the United States in international trade and commerce, and in military and other areas of international relations, of the increased use of an international standardized system of weights and measures;

(2) appraise economic and military advantages and disadvantages of the increased use of the metric system in the United States or of the increased use of such system in specific fields and the impact of such increased use upon those affected;

(3) conduct extensive comparative studies of the systems of weights and measures used in educational, engineering, manufacturing, commercial, public, and scientific areas, and the relative advantages and disadvantages, and degree of standardization of each in its respective field;

(4) investigate and appraise the possible practical difficulties which might be encountered in accomplishing the increased use of the metric system of weights and measures generally or in specific fields or areas in the United States;

(5) permit appropriate participation by representatives of United States industry, science, engineering, and labor, and their associations, in the planning and conduct of the program authorized by the first section of this Act, and in the evaluation of the information secured under such program; and

(6) consult and cooperate with other government agencies, Federal, State, and local, and, to the extent practicable, with foreign governments and international organizations.

SEC. 3. In conducting the studies and developing the recommendations required in this Act, the Secretary shall give full consideration to the advantages, disadvantages, and problems associated with possible changes in either the system of measurement units or the related dimensional and engineering standards currently used in the United States, and specifically shall—

(1) investigate the extent to which substantial changes in the size, shape, and design of important industrial products would be necessary to realize the benefits which might result from general use of metric units of measurement in the United States;

(2) investigate the extent to which uniform and accepted engineering standards based on the metric system of measurement units are in use in each of the fields under study and compare the extent to such use and the utility and degree of sophistication of such metric standards with those in use in the United States; and

(3) recommend specific means of meeting the practical difficulties and costs in those areas of the economy where any recommended change in the system of measurement units and related dimensional and engineering standards would raise significant practical difficulties or entail significant costs of conversion.

SEC. 4. The Secretary shall submit to the Congress such interim reports as he deems desirable, and within three years after the date of the enactment of this Act, a full and complete report of the findings made under the program authorized by this Act, together with such recommendations as he considers to be appropriate and in the best interests of the United States.

SEC. 5. From funds previously appropriated to the Department of Commerce, the Secretary is authorized to utilize such appropriated sums as are necessary, but not to exceed $500,000, to carry out the purposes of this Act for the first year of the program.

SEC. 6. This Act shall expire thirty days after the submission of the final report pursuant to section 3.

Approved August 9, 1968.

* * * * *

October 27, 1972, 86 Stat. 1207 (Public Law 92-573—92d Congress, 2d session) *Consumer Product Safety Act.*

This Act established the Consumer Product Safety Commission and transferred the regulatory functions of the Secretary of Commerce under the Flammable Fabrics Act and the "Refrigerator Safety Devices Act" to the Commission. The National Bureau of Standards provided technical support to the CPSC.

AN ACT

To protect consumers against unreasonable risk of injury from hazardous products, and for other purposes.

COOPERATION WITH STATES AND WITH OTHER FEDERAL AGENCIES

SEC. 29. (d) The Commission shall, to the maximum extent practicable, utilize the resources and facilities of the National Bureau of Standards, on a reimbursable basis, to perform research and analyses related to risks of injury associated with consumer products (including fire and flammability risks), to develop test methods, to conduct studies and investigations, and to provide technical advice and assistance in connection with the functions of the Commission.

TRANSFERS OF FUNCTIONS

SEC. 30. (a) The functions of the Secretary of Health, Education, and Welfare under the Federal Hazardous Substances Act (15 U.S.C. 1261 et seq.) and the Poison Prevention Packaging Act of 1970 are transferred to the Commission. The functions of the Administrator of the Environmental Protection Agency and of the Secretary of Health, Education, and Welfare under the Acts amended by subsections (b) through (f) of section 7 of the Poison Prevention Packaging Act of 1970, to the extent such functions relate to the administration and enforcement of the Poison Prevention Packaging Act of 1970, are transferred to the Commission.

(b) The functions of the Secretary of Health, Education, and Welfare, the Secretary of Commerce, and the Federal Trade Commission under the Flammable Fabrics Act (15 U.S.C. 1191 et seq.) are transferred to the Commission. The functions of the Federal Trade Commission under the Federal Trade Commission Act, to the extent such functions relate to the administration and enforcement of the Flammable Fabrics Act, are transferred to the Commission.

(c) The functions of the Secretary of Commerce and the Federal Trade Commission under the Act of August 2, 1956 (15 U.S.C. 1211) are transferred to the Commission.

(d) A risk of injury which is associated with consumer products and which could be eliminated or reduced to a sufficient extent by action taken under the Federal Hazardous Substances Act, the Poison Prevention Packaging Act of 1970, or the Flammable Fabrics Act may be regulated by the commission only in accordance with the provisions of those Acts.

(e) (1) (A) All personnel, property, records, obligations, and commitments, which are used primarily with respect to any function transferred under the provisions of subsections (a), (b) and (c) of this section shall be transferred to the Commission, except those associated with fire and flammability research in the National Bureau of Standards. The transfer of personnel pursuant to this paragraph shall be without reduction in classification or compensation for one year after such transfer, except that the Chairman of the Commission shall have full authority to assign personnel during such one-year period in order to efficiently carry out functions transferred to the Commission under this section. (86 Stat. 1231)

* * * * *

October 27, 1972, 86 Stat. 1234 (Public Law 92-574—92d Congress, 2d session) *Noise Control Act of 1972.* The Administrator of the Environmental Protection Agency was authorized to conduct research on the effects, measurement, and control of noise.

Public Law 92-574

AN ACT

To control the emission of noise detrimental to the human environment, and for other purposes.

SEC. 14 (1) (B) development of improved methods and standards for measurement and monitoring of noise, in cooperation with the National Bureau of Standards, Department of Commerce; (86 Stat. 1245)

* * * * *

September 3, 1974, 88 Stat. 1069 (Public Law 93-409—93d Congress, 2d session) *Solar Heating and Cooling Demonstration Act of 1974.*

The National Bureau of Standards was directed to determine what constituted an effective solar heating and cooling system.

Public Law 93-409

AN ACT

To provide for the early development and commercial demonstration of the technology of solar heating and combined solar heating and cooling systems.

SEC. 2. (b) It is therefore declared to be the policy of the United States and the purpose of this Act to provide for the demonstration within a three-year period of the practical use of solar heating technology, and to provide for the development and demonstration within a five-year period of the practical use of combined heating and cooling technology. (88 stat. 1069)

DEFINITIONS

SEC. 3. For purposes of this Act—

(1) the term "solar heating", with respect to any building, means the use of solar energy to meet such portion of the total heating needs of such building (including hot water), or such portion of the needs of such building for hot water (where its remaining heating needs are met by other methods), as may be required under performance criteria prescribed by the Secretary of Housing and Urban Development utilizing the services of the Director of the National Bureau of Standards, and in consultation with the Director of the National Science Foundation, and the Administrator of the National Aeronautics and Space Administration;

(2) the terms "solar heating and cooling" and "combined solar heating and cooling", with respect to any building, mean the use of solar energy to provide both such portion of the total heating needs of such building (including hot water) and such portion of the total cooling needs of such building, or such portion of the needs of such building for hot water (where its remaining heating needs are met by other methods) and such portion of the total cooling needs of a building, as may be required under performance criteria prescribed by the Secretary of Housing and Urban Development utilizing the services of the Director of the National Bureau of Standards, and in consultation with the Director of the National Science Foundation, and the Administrator of the National Aeronautics and Space Administration, and such term includes cooling by means of nocturnal heat radiation, by evaporation, or by other methods of meeting peakload energy requirements at nonpeakload times; (88 Stat. 1070)

DEVELOPMENT AND DEMONSTRATION OF SOLAR HEATING SYSTEMS TO BE USED IN RESIDENTIAL DWELLINGS

SEC. 5. (a) The Administrator and the Secretary shall promptly initiate and carry out a program, as provided in this section, for the development and demonstration of solar heating systems (including collectors, controls, and thermal storage) for use in residential dwellings.

(b) (1) Within 120 days after the date of the enactment of this Act, the Secretary, utilizing the services of the Director of the National Bureau of Standards and in consultation with the Administrator and the Director, shall determine, prescribe, and publish—

(A) interim performance criteria for solar heating components and systems to be used in residential dwellings, and

(B) interim performance criteria (relating to suitability for solar heating) for such dwellings themselves, taking into account in each instance climatic variations existing between different geographic areas.

(2) As soon as possible after the publication of the performance criteria prescribed under paragraph (1), the Secretary, in consultation with the Director of the National Bureau of Standards and the Administrator, will select on the basis of open competition a number of designs for various types of residential dwellings suitable for and adapted to the installation of solar heating systems meeting the performance criteria prescribed under paragraph (1) (A). (88 Stat. 1070)

DEVELOPMENT AND DEMONSTRATION OF COMBINED SOLAR HEATING AND COOLING SYSTEMS TO BE USED IN RESIDENTIAL DWELLINGS

SEC. 6. (a) The Administrator and the Secretary shall promptly initiate and carry out a program, as provided in this section, for the development and demonstration of combined solar heating and cooling systems (including collectors, controls, and thermal storage) for use in residential dwellings.

(b) (1) As soon as possible after the date of the enactment of this Act, the Secretary, utilizing the services of the Director of the National Bureau of Standards and in consultation with the Administrator and the Director, shall determine, prescribe, and publish—

(A) interim performance criteria for combined solar heating and cooling components and systems to be used in residential dwellings, and

(B) interim performance criteria (relating to suitability for solar heating and cooling) for such dwellings themselves, taking into account in each instance climatic variations existing between different geographic areas.

(2) As soon as possible after the publication of the performance criteria prescribed under paragraph (1) (and if possible before the completion of the research and development provided for in subsection (c)), the Secretary, in consultation with the Director of the National Bureau of Standards and the Administrator, will select on the basis of open competition a number of designs for various types of residential dwellings suitable for and adapted to the installation of combined solar heating and cooling systems meeting the performance criteria prescribed under paragraph (1) (A). (88 Stat. 1072)

DEVELOPMENT AND DEMONSTRATION OF SOLAR HEATING AND COMBINED SOLAR HEATING AND COOLING SYSTEMS FOR COMMERCIAL BUILDINGS

SEC. 9. The Administrator, in consultation with the Secretary, the Director, the Administrator of General Services, and the Director of the National Bureau of Standards and concurrently with the conduct of the programs under sections 5 and 6, shall enter into arrangements with appropriate Federal agencies to carry out such projects and activities (including demonstration projects) with respect to apartment buildings, office buildings, factories, crop-drying facilities and other agricultural structures, public buildings (including schools and colleges), and other non-residential, commercial, or industrial buildings, taking into account the special needs of and individual differences in such buildings based upon size, function, and other relevant factors, as may be appropriate for the early development and demonstration of solar heating and combined solar heating and cooling systems suitable and effective for use in such buildings. (88 Stat. 1074)

COORDINATION, MONITORING, AND LIAISON

SEC. 11. (a) The Secretary, utilizing the services of the Director of the National Bureau of Standards and in coordination with such other Government agencies as may be appropriate, shall—

(1) monitor the performance and operation of solar heating and combined solar heating and cooling systems installed in residential dwellings under this Act;

(2) collect and evaluate data and information on the performance and operation of solar heating and combined solar heating and cooling systems installed in residential dwellings under this Act; and

(3) from time to time, carrying out such studies and investigations and take such other actions, including the submission of special reports to the Congress when appropriate, as may be necessary to assure that the programs for which the Secretary is responsible under this Act effectively carry out the policy of this Act. (88 Stat. 1074)

DISSEMINATION OF INFORMATION AND OTHER ACTIONS TO PROMOTE PRACTICAL USE OF SOLAR HEATING AND COOLING TECHNOLOGIES

SEC. 12. (a) The Secretary shall take all possible steps to assure that full and complete information with respect to the demonstrations and other activities conducted under this Act is made available to Federal, State, and local authorities, the building industry and related segments of the economy, the scientific and technical community, and the public at large, both during and after the close of the programs under this Act, with the objective of promoting and facilitating to the maximum extent feasible the early and widespread practical use of solar energy for the heating and cooling of buildings throughout the United States. In accordance with regulations prescribed under section 16 such information shall be disseminated on a coordinated basis by the Secretary, the Administrator, the Director of the National Bureau of Standards, the Director, the Commissioner of the Patent Office, and other appropriate Federal offices and agencies. (88 Stat. 1075)

REGULATIONS

SEC. 16. The Administrator and the Secretary in consultation with the Director of the National Bureau of Standards, the Director, the Administrator of the General Services Administration, the Secretary of Defense, and other appropriate officers and agencies, shall prescribe such regulations as may be necessary or appropriate to carry out this Act promptly and efficiently. Each such officer or agency, in consultation with the Administrator and the Secretary, may prescribe such regulations as may be necessary or appropriate to carry out his or its particular functions under this Act promptly and efficiently. (88 Stat. 1078).

* * * * *

October 29, 1974, 88 Stat. 1535 (Public Law 93-498—93d Congress, 2d session) *Federal Fire Prevention and Control Act of 1974.*

The establishment of the Center for Fire Research reorganized and strengthened the fire research programs at the National Bureau of Standards.

Public Law 93-498

AN ACT

To reduce losses of life and property, through better fire prevention and control, and for other purposes.

PURPOSES

SEC. 3. It is declared to be the purpose of Congress in this Act to—

(1) reduce the Nation's losses caused by fire through better fire prevention and control;

(2) supplement existing programs of research, training, and activities by State and local governments;

(3) establish the National Fire Prevention and Control Administration and the Fire Research Center within the Department of Commerce; and

(4) establish an intensified program of research into the treatment of burn and smoke injuries and the rehabilitation of victims of fires within the National Institutes of Health. (88 Stat. 1536)

FIRE RESEARCH CENTER

SEC. 18. The Act of March 3, 1901 (15 U.S.C. 278), is amended by striking out sections 16 and 17 (as added by title I of the Fire Prevention and Control Act of 1968) and by inserting in lieu thereof the following new section:

"SEC. 16. (a) There is hereby established within the Department of Commerce a Fire Research Center which shall have the mission of performing and supporting research on all aspects of fire with the aim of providing scientific and technical knowledge applicable to the prevention and control of fires. The content and priorities of the research program shall be determined in consultation with the Administrator of the National Fire Prevention and Control Administration. In implementing this section, the Secretary is authorized to conduct, directly or through contracts or grants, a fire research program, including—

"(1) basic and applied fire research for the purpose of arriving at an understanding of the fundamental processes underlying all aspects of fire. Such research shall include scientific investigations of—

"(A) the physics and chemistry of combustion processes;

"(B) the dynamics of flame ignition, flame spread, and flame extinguishment;

"(C) the composition of combustion products developed by various sources and under various environmental conditions;

"(D) the early stages of fires in buildings and other structures, structural subsystems and structural components in all other types of fires, including, but not limited to, forest fires, brush fires, fires underground, oil blowout fires, and water-borne fires, with the aim of improving early detection capability;

"(E) the behavior of fires involving all types of buildings and other structures and their contents (including mobile homes and highrise buildings, construction materials, floor and wall coverings, coatings, furnishings, and other combustible materials), and all other types of fires, including forest fires, brush fires, fires underground, oil blowout fires, and waterborne fires;

"(F) the unique fire hazards arising from the transportation and use, in industrial and professional practices, of combustible gases, fluids, and materials;

"(G) design concepts for providing increased fire safety consistent with habitability, comfort, and human impact in buildings and other structures; and

"(H) such other aspects of the fire process as may be deemed useful in pursuing the objectives of the fire research program;

"(2) research into the biological, physiological, and psychological factors affecting human victims of fire, and the performance of individual members of fire services, including—

"(A) the biological and physiological effects of toxic substances encountered in fires;

"(B) the trauma, cardiac conditions, and other hazards resulting from exposure to fire;

"(C) the development of simple and reliable tests for determining the cause of death from fires;

"(D) improved methods of providing first aid to victims of fires;

"(E) psychological and motivational characteristics of persons who engage in arson, and the prediction and cure of such behavior;

"(F) the conditions of stress encountered by firefighters, the effects of such stress, and the alleviation and reduction of such conditions; and

"(G) such other biological, psychological, and physiological effects of fire as have significance for purposes of control or prevention of fires; and

"(3) operation tests, demonstration projects, and fire investigations in support of the activities set forth in this section.

"The Secretary shall insure that the results and advances arising from the work of the research program are disseminated broadly. He shall encourage the incorporation, to the extent applicable and practicable, of such results and advances in building codes, fire codes, and other relevant codes, test methods, fire service operations and training, and standards. The Secretary is authorized to encourage and assist in the development and adoption of uniform codes, test methods, and standards aimed at reducing fire losses and costs of fire protection.

"(b) For the purposes of this section there is authorized to be appropriated not to exceed $3,500,000 for the fiscal year ending June 30, 1975 and not to exceed $4,000,000 for the fiscal year ending June 30, 1976." (88 Stat. 1545).

* * * * *

December 31, 1974, 88 Stat. 1878 (Public Law 93-577—93d Congress, 2d session) *Federal Nonnuclear Energy Research and Development Act of 1974.*

The Office of Energy Related Inventions was established to help the Energy Research and Development Administration evaluate non-nuclear energy ideas.

Public Law 93-577

AN ACT

To establish a national program for research and development in nonnuclear energy sources.

ENERGY-RELATED INVENTIONS

SEC. 14. The National Bureau of Standards shall give particular attention to the evaluation of all promising energy-related inventions, particularly those submitted by individual inventors and small companies for the purpose of obtaining direct grants from the Administrator. The National Bureau of Standards is authorized to promulgate regulations in the furtherance of this section. (88 Stat. 1894)

* * * * *

December 22, 1975, 89 Stat. 871 (Public Law 94-163—94th Congress, 1st session) Energy Policy and Conservation Act.

Public Law 94-163

AN ACT

To increase domestic energy supplies and availability; to restrain energy demand; to prepare for energy emergencies; and for other purposes.

SEC. 323. (a) (2-5) (89 Stat. 919) Test Procedures.... The Administrator shall direct the National Bureau of Standards to develop test procedures for the determination of (A) estimated annual operating costs of covered products of the types specified......

SEC. 383. (c) (89 Stat. 940) Federal Actions with Respect to Recycled Oil.

As soon as practicable after the date of enactment of this Act, the National Bureau of Standards shall develop test procedures for the determination of substantial equivalency of re-refined or otherwise processed used oil or blend of oil, consisting of such re-refined or otherwise processed used oil and new oil or additives, with new oil for a particular end use. As soon as practicable after development of such test procedures, the National Bureau of Standards shall report such procedures to the Commission.

* * * * *

December 23, 1975, 89 Stat. 1007 (Public Law 94-168—-94th Congress, 1st session) Metric Conversion Act of 1975.

Public Law 94-168

AN ACT

To declare a national policy of coordinating the increasing use of the metric system in the United States, and to establish a United States Metric Board to coordinate the voluntary conversion to the metric system.

SEC. 5. (a) (89 Stat. 1007) There is established , in accordance with this section, an independent instrumentality to be known as a United States Metric Board.

SEC. 6. (7) (C) (89 Stat. 1010) ... consultation by the Secretary of Commerce with the National Conference of Weights and Measures in order to assure that State and local weights and measures officials are (i) appropriately involved in metric conversion activities and (ii) assisted in their efforts to bring about timely amendments to weights and measures laws.

* * * * *

May 11, 1976, 90 Stat. 459 (Public Law 94-282—-94th Congress, 2d session) National Science and Technology Policy, Organization, and Priorities Act of 1976.

Public Law 94-282

AN ACT

To establish a science and technology policy for the United States, to provide for scientific and technological advice and assistance to the President, to provide a comprehensive survey of ways and means for improving the Federal effort in scientific research and information handling, and in the use thereof, to amend the National Science Foundation Act of 1950, and for other purposes.

SEC. 201. (90 Stat. 463) This title may be cited as the "Presidential Science and Technology Advisory Organization of 1976" .

SEC. 202. (90 Stat. 463) There is established in the Executive Office of the President an Office of Science and Technology Policy.

SEC. 205.(b)(1) (90 Stat. 465) The Director [of OSTP] shall establish an Intergovernmental Science, Engineering and Technology Panel, whose purpose shall be to (A) identify and define civilian problems at State, regional, and local levels which science, engineering, and technology may assist in resolving or ameliorating; (B) recommend priorities for addressing such problems; and (C) advise and assist the Director in identifying and fostering policies to facilitate the transfer and utilization of research and development results so as to maximize their application to civilian needs.

SEC. 301. (90 Stat. 468) The President shall establish within the Executive Office of the President a President's Committee on Science and Technology.

SEC. 401.(a) (90 Stat. 471) There is established the Federal Coordinating Council for Science, Engineering and Technology.

SEC. 402. The Federal Council for Science, and Technology established ... March 13, 1959 ... is hereby abolished.

* * * * *

August 14, 1976, 90 Stat. 1125 (Public Law 94-385—-94th Congress, 2d session) Energy Conservation and Production Act.

Public Law 94-385

AN ACT

To amend the Federal Energy Administration Act of 1974 to extend the duration of authorities under such Act; to provide an incentive for domestic production; to provide for electric utility rate design initiatives; to provide for energy conservation standards for new buildings; to provide for energy conservation assistance for existing buildings and industrial plants; and for other purposes.

SEC. 161. (a) (1) (A) (90 Stat.1140) The Administrator shall direct the National Bureau of Standards to develop an energy efficiency improvement target for each type of covered product ...

SEC. 304. (a) (1-2) (90 Stat.1146) [Director of the National Bureau of Standards is to be consulted in the proposed performance standards for new commercial and residential buildings]

SEC. 310. (90 Stat. 1149) The Secretary, in cooperation with the Administrator, the Secretary of Commerce utilizing the services of the Director of the National Bureau of Standards, and the heads of other appropriate Federal agencies, and the National Institute of Building Sciences, shall carry out any activities which the Secretary determines may be necessary or appropriate to assist in the development of performance standards under section 304(a) and to facilitate the implementation of such standards by State and local governments.

SEC. 413. (b) (2) (A) (90 Stat. 1153) The regulations promulgated pursuant to this section shall include provisions prescribing, in coordination with the Secretary of Housing and Urban Development, the Secretary of Health, Education, and Welfare, and the Director of the National Bureau of Standards in the Department of Commerce, for use in various climatic, structural, and human need settings, standards for weatherization materials, energy conservation techniques, and balanced combinations thereof, which are designed to achieve a balance of a healthful dwelling environment and maximum practicable energy conservation.

* * * * *

October 21, 1976, 90 Stat. 2795 (Public Law 94-580—-94th Congress, 2d session) Resource Conservation and Recovery Act of 1976.

Public Law 94-580

AN ACT

To provide technical and financial assistance for the development of management plans and facilities for the recovery of energy and other resources from discarded materials and for the safe disposal of discarded materials, and to regulate the management of hazardous waste.

SEC. 5002. (90 Stat. 2820) The Secretary of Commerce, acting through the National Bureau of Standards ... shall ... publish guidelines for the development of specifications for the classification of materials recovered from waste which were destined for disposal.

SEC. 6002. (e) (90 Stat. 2822)....National Bureau of Standards...shall prepare and from time to time revise, guidelines......

* * * * *

August 7, 1977, 91 Stat. 685 (Public Law 95-95—-95th Congress, 1st session) Clean Air Act Amendments of 1977.

Public Law 95-95

AN ACT

To amend the Clean Air Act, and for other purposes.

SEC. 320. (b) (91 Stat. 782) The [air quality modeling] conference conducted shall provide for participation by.... National Bureau of Standards.

* * * * *

October 7, 1977, 91 Stat. 1098 (Public Law 95-124—-95th Congress, 1st session) Earthquake Hazards Reduction Act of 1977.

Public Law 95-124

AN ACT

To reduce the hazards of earthquakes, and for other purposes.

SEC. 5. (d) (91 Stat. 1101) Participation.—- In assigning the role and responsibility of Federal departments, agencies, and entities ... the President shall ... include ... the National Bureau of Standards.

* * * * *

November 9, 1977, 91 Stat. 1290 (Public Law 95-164—-95th Congress, 1st session) Federal Mine Safety and Health Amendments Act of 1977.

Public Law 95-164

AN ACT

To promote safety and health in the mining industry, to prevent recurring disasters in the mining industry, and for other purposes.

SEC. 102. (91 Stat. 1295) Advisory Committees . The Secretary of the Interior shall appoint an advisory committee on coal or other mine safety research composed of (B)... the Director of the National Bureau of Standards.

* * * * *

November 4, 1978, 92 Stat. 2513 (Public Law 95-590—95th Congress, 2d session) Solar Photovoltaic Energy Research, Development, and Demonstration Act of 1978.

Public Law 95-590

AN ACT

To provide for an accelerated program of research, development, and demonstration of solar photovoltaic energy technologies leading to early competitive commercial applicabilty of such technologies to be carried out by the Department of Energy, with support of the National Aeronautics and Space Administration, the National Bureau of Standards, the General Services Administration, and other federal agencies.

* * * * *

November 9, 1978, 92 Stat. 3206 (Public Law 95-619—95th Congress, 2d session) National Energy Conservation Policy Act.

Public Law 95-619

AN ACT

To improve the energy conservation policy.

SEC. 212. (a) (92 Stat. 3211) Promulgation of Rules by Secretary- The Secretary shall....publish an advanced notice of proposed rulemaking with respect to rules on the content and implementation of residential energy conservation plans...after consultation with...the Secretary of Commerce (acting through the National Bureau of Standards)..., the Secretary shall publish a proposed rule on content and implementation of such plans.

SEC.222. (92 Stat. 3223) Product Standards. The Secretary shall consult with the Secretary of Commerce, acting through the National Bureau of Standards, with regards to any product or material standard which is relied on in implementing this Part as a basis for judging the efficiency, energy efficiency, safety, or other attributes of energy conservation materials, products, or devices...

SEC.545. (a) (92 Stat. 3278). Establishment of Life Cycle Cost Methods. The Secretary in consultation with...the Director of the National Bureau of Standards....shall (1) establish practical and effective methods for estimating and comparing life cycle costs for Federal buildings; and (2) develop and prescribe the procedures to be followed in applying and implementing the methods so established and in conducting preliminary energy audits required by section 547.

SEC.546 . Energy Performance Targets for Federal Buildings. The Secretary, in consultation with....the Director of the National Bureau of Standards....shall establish and publish energy performance targets for Federal buildings, and shall take such actions as may be necessary or appropriate to promote to the maximum extent practicable achievement of such targets by Federal buildings.

* * * * *

July 26, 1979, 93 Stat. 144 (Public Law 96-39—96th Congress, 1st session)
Trade Agreements Act of 1979.

Public Law 96-39

AN ACT

To approve and implement the trade agreements negotiated under the Trade Act of 1974, and for other purposes.

SEC. 414. (93 Stat. 245) Standards Information Center. (a) Establishment- The Secretary of Commerce shall maintain within the Department of Commerce a standards information center. (b) Functions.-The standards information center shall-(1) serve as the central national collection facility for information relating to standards, certification systems, and standards-related activities, whether such standards, systems, or activities are public or private, domestic or foreign, or international, regional, national, or local; (2) make available to the public at such reasonable fee as the Secretary shall prescribe, copies of information required to be collected under paragraph (1) other than information to which paragraph (3) applies; (3) use its best efforts to make available to the public, at such reasonable fees as the Secretary shall prescribe, copies of information required to be collected under paragraph (1) that is of private origin, on a cooperative basis with the private individual or entity, foreign or domestic, who holds the copyright on the information; (4) in case of such information that is of foreign origin, provide, at such reasonable fee as the Secretary shall prescribe, such translation services as may be necessary; (5) serve as the inquiry point for requests for information regarding standards-related activities, whether adopted or proposed, within the United States, except that in carrying out this paragraph, the Secretary of Commerce shall refer all inquiries regarding agricultural products to the technical office established under section 412(a)(2) within the Department of Agriculture; and (6) provide such other services as may be appropriate, including but not limited to, such services to the technical offices established under section 412 as may be requested by those offices carrying out their functions.

* * * * *

November 16, 1979, 93 Stat. 863 (Public Law 96-121—96th Congress, 1st session) Authorization, Appropriations-Federal Fire Prevention and Control Act of 1974.

Public Law 96-121

AN ACT

To authorize appropriations for the Federal Fire Prevention and Control Act of 1974, and for other purposes.

SEC. 3. (93 Stat. 863) Section 16(b) of the Act entitled "An Act to establish the National Bureau of Standards", approved March 3, 1901 (15 U.S.C. 278f(b)), is amended to read as follows: "(b) Authorization of Appropriations.-For purposes of this section, there are authorized to be appropriated an amount not to exceed $5,650,000 for the fiscal year ending September 30, 1980, which amount includes-"(l) $525,000 for programs which are recommended in the report submitted to the Congress by the Administrator of the United States Fire Administration pursuant to section 24(b)(1) of the Federal Fire Prevention and Control Act of 1974 (15 U.S.C. 2220(b)(1); and "(2) $119,000 for adjustments required by law in salaries, pay, retirement, and employee benefits."

* * * * *

January 8, 1980, 93 Stat. 1339 (Public Law 96-187—96th Congress, 1st session) Federal Election Campaign Act Amendments of 1979.

Public Law 96-187

AN ACT

To amend the Federal Election Campaign Act of 1971 to make certain changes in the reporting and disclosure requirements of such act, and for other purposes.

SEC. 302. (93 Stat. 1368) Voting System Study. The Federal Election Commission, with the cooperation and assistance of the National Bureau of Standards, shall conduct a preliminary study with respect to the future development of voluntary engineering and procedural performance standards for voting systems used in the United States.

* * * * *

October 15, 1980, 94 Stat. 2049 (Public Law 96-461—96th Congress, 2d session) National Bureau of Standards Authorization Act for Fiscal Years 1981 and 1982.

Public Law 96-461

AN ACT

To authorize appropriations to the Secretary of Commerce for the programs of the National Bureau of Standards for fiscal years 1981 and 1982, and for other purposes.

SEC. 2. (a) (94 Stat. 2049) There are hereby authorized to be appropriated to the Secretary of Commerce, hereinafter referred to as the Secretary, to carry out activities performed by the National Bureau of Standards.

SEC. 8 . (94 Stat. 2051) Facilities Improvement. Section 14 of the Act of March 3, 1901..is further amended....

SEC. 9. (94 Stat. 2051) International Activities. In order to develop and strengthen the expertise of the National Bureau of Standards in science and engineering, to enhance the Secretary's ability to maintain the Bureau's programs at the forefront of worldwide developments in science and engineering, and to cooperate in international scientific activities, the Act of March 3, 1901 (15 U.S.C. 271-278h), as amended, is further amended by inserting immediately after section 16 the following new section: "Sec. 17. (a) The Secretary is authorized, notwithstanding any other provision of law, to expend such sums, within the limit of appropriated funds, as the Secretary may deem desirable, through the grant of fellowships or any other form of financial assistance, to defray the expenses of foreign nationals not in service to the Government of the United States while they are performing scientific or engineering work at the National Bureau of Standards or participating in the exchange of scientific or technical information at the National Bureau of Standards. "(b) The Congress consents to the acceptance by employees of the National Bureau of Standards of fellowships, lectureships, or other positions for the performance of scientific or engineering activities or for the exchange of scientific or technical information, offered by a foreign government, and to the acceptance and retention by an employee of the National Bureau of Standards of any form of financial or other assistance provided by a foreign government as compensation for or as a means of defraying expenses associated with the performance of scientific or engineering activities or the exchange of scientific or technical information, in any case where the acceptance of such fellowship, lectureship, or position or the acceptance and retention of such assistance is determined by the Secretary to be appropriate and consistent with the interests of the United States. For the purposes of this subsection, the definitions appearing in section 7342(a) of title 5 of the United States code apply. Civil actions may be brought and penalties assessed against any employee who knowingly accepts and retains assistance from a foreign government not consented to by this subsection in the same manner as is prescribed by section 7342(h) of title 5 of the United States Code. "(c) Provisions of law prohibiting the use of any part of any appropriation for the payment of compensation to any employee or officer of the Government of the United States who is not a citizen of the United States shall not apply to the payment of compensation to scientific or engineering personnel of the National Bureau of Standards."

* * * * *

October 15, 1980, 94 Stat. 2055 (Public Law 96-463—96th Congress, 2d session) Used Oil Recycling Act of 1980.

Public Law 96-463

AN ACT

To amend the Solid Waste Disposal Act to further encourage the use of recycled oil.

SEC. 9. (94 Stat. 2058) Study. The Administrator of the Environmental Protection Agency, in cooperation with the Secretary of Energy, the Federal Trade Commission, and the Secretary of Commerce, shall conduct a study (1) assessing environmental problems associated with improper disposal or reuse of used oil...

* * * * *

October 19, 1980, 94 Stat. 2257 (Public Law 96-472—-96th Congress, 2d session) Earthquake Hazards Reduction and Fire Prevention and Control Program.

Public Law 96-472

AN ACT

To amend the Earthquake Hazards Reduction Act of 1977 and the Federal Fire Prevention and Control Act of 1974 to authorize the appropriation of funds to the Director of the Federal Emergency Management Agency to carry out the earthquake hazards reduction program and the fire prevention and control program and for other purposes.

SEC. 6. (d) (94 Stat. 2259) National Bureau of Standards- To enable the Bureau to carry out responsibilities that may be assigned to it under this Act, there are authorized to be appropriated $425,000 for the fiscal year ending September 30, 1981.

Sec. 201 (c) (3) (94 Stat. 2260) not less than $4,255,000 for research and development for the activities under section 18 of this Act at the Fire Research Center of the National Bureau of Standards....

* * * * *

October 21, 1980, 94 Stat. 2311 (Public Law 96-480—-96th Congress, 2d session) Stevenson-Wydler Technology Innovation Act of 1980.

Public Law 96-480

AN ACT

To promote United States technological innovation for the achievement of national economic, environmental, and social goals, and for other purposes. Promotes U.S. technological innovation for the achievement of national economic, environmental, and social goals. Requires Secretary of Commerce to establish and maintain an Office of Industrial Technology and establishes National Technology Medal.

SEC. 6. (a) (94 Stat. 2313) Establishment.—-The Secretary shall provide assistance for the establishment ol Centers for Industrial Technology. Such Centers shall be affiliated with any university, or other nonprofit institution, or group thereof, that applies for and is awarded a grant or enters into a cooperative agreement under this section.

SEC. 11. (b) (94 Stat. 2318) Establishment of Research and Technology Applications Offices.—-Each Federal laboratory shall establish an Office of Research and Technology Applications.

SEC. 12. (a) (94 Stat. 2319) Establishment.—-There is hereby established a National Technology Medal.....

* * * * *

November 20, 1981, 95 Stat. 1081 (Public Law 97-80—-97th Congress, 1st session) Authorization, Appropriations-Earthquake Hazards Reduction and Fire Prevention and Control Program.

Public Law 97-80

AN ACT

To amend the Earthquake Hazards Reduction Act of 1977 and the Federal Fire Prevention and Control Act of 1974 to authorize the appropriation of funds to the Director of the Federal Emergency Management Agency to carry out the earthquake hazards reduction programs and the fire prevention and control program, and for other purposes.

SEC. 201 (95 Stat. 1081-82) Section 17 of the Federal Fire Prevention and Control Act of 1974 is amended by adding at the end thereof the following: "(d) Except as otherwise specifically provided with respect to the payment of claims under section 11 of this Act, to carry out the purposes of this Act, there are authorized to be appropriated-"(l) $20,815,000 for the fiscal year ending September 30, 1982, and $23,312,800 for the fiscal year ending September 30, 1983, which amount shall include-"(A) such sums as may be necessary for the support of research and development at the Fire Research Center of the National Bureau of Standards under section 18 of this Act, which sums shall be in addition to those funds authorized to be appropriated under the National Bureau of Standards Authorization Act for fiscal years 1981 and 1982;"...

* * * * *

October 6, 1982, 96 Stat. 1222 (Public Law 97-286—-97th Congress, 2d session) National Bureau of Standards Authorization Act for Fiscal Year 1983.

Public Law 97-286

AN ACT

To authorize appropriations to the Secretary of Commerce for the programs of the National Bureau of Standards for fiscal year 1983, and for other purposes.

SEC. 2 (a) (96 Stat. 1222) There are hereby authorized to be appropriated to the Secretary of Commerce, hereinafter referred to as the Secretary, to carry out activities performed by the National Bureau of Standards, the sums set forth in the following line items: (1) Measurement Research and Standards, for fiscal year 1983, $50,389,000. (2) Engineering Measurements and Standards, for fiscal year 1983, $20,807,000. (3) Computer Science and Technology, for fiscal year 1983, $10,000,000. (4) Core Research Program for Innovation and Productivity, for fiscal year 1983, $11,188,000. (5) Technical Competence Fund, for fiscal year 1983, $6,986,000. (6) Fire Research Center, for fiscal year 1983, $4,991,000. (7) Central Technical Support, for fiscal year 1983, $13,500,000. (b) Notwithstanding any other provision of this or any other Act, for fiscal year 1983: (1) of the total amount authorized under subsection (a)(4) not less than $3,000,000 shall be available for "Metals Processing"; (2) of the total amounts authorized under subsections (a)(1) and (a)(2), not less than $1,000,000 shall be available for "Measurement Standards for the Handicapped"; (3) of the total amount authorized under subsection (a)(3), not less than $10,000,000 shall be available for "Computer Science and Technology"; and (4) of the total amount authorized under subsection (a)(4), $3,200,000 for "Robotics Research and Development".

SEC. 3. (96 Stat. 1222) In addition to the sums authorized in section 2, not more than $500,000 is authorized for fiscal year 1983 for expenses of the National Bureau of Standards incurred outside the United States, to be paid for in foreign currencies that the Secretary of the Treasury determines to be excess to the normal requirements of the United States.

SEC. 8. (96 Stat. 1223) The Secretary of Commerce shall charge for any service performed by the Bureau, at the request of another Government agency....

* * * * *

January 6, 1983, 96 Stat. 2097 (Public Law 97-424—-97th Congress, 2d session) Surface Transportation Assistance Act of 1982.

Public Law 97-424

AN ACT

To authorize appropriations for construction of certain highways in accordance with title 23, United States Code, for highway safety, for mass transportation in urban and rural areas, and for other purposes.

SEC. 110. (c)(1) (96 Stat. 2105) The Secretary of Transportation is directed to coordinate a study with the National Bureau of Standards, the American Society for Testing and Materials and other organizations as deemed appropriate, to determine existing quality of design, need for uniform standards and costs for highway systems and bridges.

* * * * *

July 16, 1984, 98 Stat. 431 (Public Law 98-362—98th Congress, 2d session)
Small Business Computer Security and Education Act of 1984.

Public Law 98-362

AN ACT

To amend the Small Business Act to establish a small business computer security and education advisory council, and for other purposes.

SEC. 3. (B) (98 Stat. 432) The advisory council shall consist of the following members:... (ii) an official of the Institute for Computer Sciences and Technology of the Department of Commerce, appointed by the Secretary of Commerce.

* * * * *

October 30, 1984, 98 Stat. 2925 (Public Law 98-567—98th Congress, 2d session) Cigarette Safety Act of 1984.

Public Law 98-567

AN ACT

To establish an interagency committee and a technical study group on cigarette safety.

SEC.3. (a) (1) . (98 Stat. 2925) ... one scientific or technical representative each from...the Center for Fire Research of the National Bureau of Standards...

* * * * *

July 29, 1985, 99 Stat. 171 (Public Law 99-73—99th Congress, 1st session)
National Bureau of Standards Authorization Act for Fiscal Year 1986.

Public Law 99-7

AN ACT

To authorize appropriations to the Secretary of Commerce for the programs of the National Bureau of Standards for fiscal year 1986, and for other purposes.

SEC. 2. (a) (99 Stat. 171) Authorizations for Program Activities. There are authorized to be appropriated to the Secretary of Commerce for fiscal year 1986, to carry out activities performed by the National Bureau of Standards, the sums set forth in the following line items: (1) Measurement Research and Standards, $36,843,000. (2) Materials Science and Engineering, $21,943,000. (3) Engineering Measurements and Standards, $33,555,000. (4) Computer Science and Technology, $9,657,000. (5) Center for Fire Research, $5,827,000. (6) Technical Competence Fund, $8,481,000. (7) Central Technical Support, $8,179,000.

(b) Notwithstanding any other provision of this or any other Act for fiscal year 1986- (1) ...$2,000,000 is authorized only for steel technology; (2)....$3,895,000 is authorized only for the Center for Building Technology, and $50,000 is authorized only for the purpose of assisting the creation and maintenance of data bases on structural failures; and (3)...$2,575,00 is authorized for transfer to the Working Capital Fund....(d) The National Bureau of Standards shall seek reimbursements of not less than $500,000 from other Federal agencies to expand its efforts in support of basic scientific research on the atmospheric, climatic, and environmental consequences of nuclear explosions and nuclear exchanges.

SEC. 7. (99 Stat. 173) Structural Failures. The National Bureau of Standards, on its own initiative but only after consultation with local authorities, may initiate and conduct investigations to determine the causes of structural failures in structures which are used or occupied by the general public.

* * * * *

October 20, 1986, 100 Stat. 1785 (Public Law 99-502—99th Congress, 2d session) Federal Technology Transfer Act of 1986.

Public Law 99-502

AN ACT

To amend the Stevenson-Wydler Technology Innovation Act of 1980 to promote technology transfer by authorizing Government-operated laboratories to enter into cooperative research agreements and by establishing a Federal Laboratory Consortium for Technology Transfer within the National Bureau of Standards, and for other purposes.

SEC. 3. (e) (1) (100 Stat. 1787) Establishment of Federal Laboratory Consortium for Technology Transfer—- There is hereby established the Federal Laboratory Consortium for Technology Transfer.

SEC. 3. (e) (4) (100 Stat. 1788) The Director of the National Bureau of Standards shall provide the Consortium, on a reimbursable basis, with administrative services, such as office space, personnel, and support services of the Bureau, as requested by the Consortium and approved by such Director.

* * * * *

October 22, 1986, 100 Stat. 2970 (Public Law 99-519—99th Congress, 1st session) Asbestos Hazard Emergency Response Act of 1986.

Public Law 99-519

AN ACT

To amend the Toxic Substances Control Act to require the Environmental Protection Agency to promulgate regulations requiring inspection for asbestos-containing materials in the Nation's schools, development of asbestos management plans for such schools, response actions with respect to friable asbestos-containing material in such schools, and for other purposes.

SEC. 206. (d)(2) (100 Stat. 2982) The National Bureau of Standards...shall...develop an accreditation program for laboratories which conduct qualitative and semi-quantitative analysis of bulk samples of asbestos-containing material, and develop an accreditation program for laboratories which conduct analysis of air samples of asbestos from school buildings under the authority of a local educational agency.

* * * * *

October 28, 1986, 100 Stat. 3236 (Public Law 99-574—99th Congress, 2d session) National Bureau of Standards Authorization Act for Fiscal Year 1987.

Public Law 99-574

AN ACT

To authorize appropriations to the Secretary of Commerce for the programs of the National Bureau of Standards for fiscal year 1987, and for other purposes.

SEC. 2 (a) (100 Stat. 3236) There are authorized to be appropriated to the Secretary of Commerce for fiscal year 1987, to carry out the activities performed by the National Bureau of Standards, the sums set forth in the following line items: (1) Measurement Research and Standards, $36,582,000; (2) Materials Science and Engineering, $21,228,000; (3) Engineering Measurements and Standards, $35,875,000; (4) Computer Science and Technology, $7,500,00; and (5) Research Support Activities, $22,768,000.

(b)(1)...$1,900,000 is authorized only for steel technology; (2)...$3,470,000 is authorized only for the Center for Building Technology and $5,402,000 is authorized only for the Center for Fire Research; (3)...$1,000,000 is authorized only for Computer Security Activities; (4)...$6,763,000 is authorized only for the Technical Competence Fund; and (5)..$6,500,000 is authorized only for the design, equipment, and construction of the Cold Neutron Research Facility.

SEC. 6. (a) (100 Stat. 3237) Financial Assistance to Current and Prospective Employees....."Sec. 18. The Director is authorized to expend up to 1 per centum of the funds appropriated for activities of the National Bureau of Standards in any fiscal year, as the Director may deem desirable, for awards of research fellowships and other forms of financial assistance to students at institutions of higher learning within the United States who show promise as present or future contributors to the mission of the Bureau....

SEC. 7. (100 Stat. 3237) Assessment of Emerging Technologies Requiring Research in Metrology. The Board of Assessment of the National Bureau of Standards programs shall include, as part of its annual review, an assessment of emerging technologies which are expected to require research in metrology to keep the Bureau abreast of its mission....

SEC. 8. (a) (100 Stat. 3238) Post-Doctoral Fellowship Program...."Sec. 19. The National Bureau of Standards, in conjunction with the National Academy of Sciences, shall establish and conduct a post-doctoral fellowship program...

SEC. 9. (a) (100 Stat. 3238) Process and Quality Control and Calibration Programs. The Director of the National Bureau of Standards shall hold discussions with representatives of Federal agencies....which use the process and quality control and calibration programs of the Bureau, and with ...private sector, in order to determine the extent of the demand for research and services under such programs...

SEC.10. (a)(1) (100 Stat. 3238) Demonstration Project Relating to Personnel Management. The Office of Personnel Management and the National Bureau of Standards shall jointly design a demonstration project which shall be conducted by the Director of the National Bureau of Standards.

* * * * *

November 17, 1986, 100 Stat. 4082 (Public Law 99-662—-99th Congress, 2d session) Water Resources Development Act of 1986.

Public Law 99-662

AN ACT

To provide for the conservation and development of water and related resources and the improvement and rehabilitation of the Nation's water resources infrastructure.

SEC. 1201. (b) (100 Stat. 4262) The Secretary, in cooperation with the National Bureau of Standards, shall undertake a program of research in order to develop improved techniques and equipment for rapid and effective dam inspection, together with devices for the continued monitoring of dams for safety purposes.

* * * * *

March 17, 1987, 101 Stat. 103 (Public Law 100-12—-100th Congress, 1st session) National Appliance Energy Conservation Act of 1987.

Public Law 100-12

AN ACT

To amend the Energy Policy and Conservation Act with respect to energy conservation standards for appliances.

SEC. 323(C) (101 Stat. 106) The Secretary shall direct the National Bureau of Standards to assist in developing new or amended test procedures.

* * * * *

August 20, 1987, 101 Stat. 724 (Public Law 100-107—100th Congress, 1st session) Malcolm Baldrige National Quality Improvement Act of 1987.

Public Law 100-107

AN ACT

To amend the Stevenson-Wydler Technology Innovation Act of 1980 to establish the Malcolm Baldrige National Quality Award, with the objective of encouraging American business and other organizations to practice effective quality control in the provision of their goods and services.

SEC. 2. (b) (101 Stat. 725) Purpose.—It is the purpose of this Act to provide for the establishment and conduct of a national quality improvement program under which (1) awards are given to selected companies and other organizations in the United States that practice effective quality management and as a result make significant improvements in the quality of their goods and services, and (2) information is disseminated about the successful strategies and programs.

SEC. 3. (101 Stat. 726) Establishment of the Malcolm Baldrige National Quality Award Program...."Sec. 16. (d) Criteria for Qualification.-(1) An organization may qualify for an award under this section only if it-"(A) applied to the Director of the National Bureau of Standards in writing, for the award....

* * * * *

January 8, 1988, 101 Stat. 1724 (Public Law 100-235—100th Congress, 1st session) Computer Security Act of 1987.

Public Law 100-235

AN ACT

To provide for a computer standards program within the National Bureau of Standards, to provide for Government-wide computer security, and to provide for the training in security matters of persons who are involved in the management, operation, and use of Federal computer systems, and for other purposes.

SEC. 3. (101 Stat. 1724-1725) Establishment of Computer Standards Program. The Act of March 3, 1901 is amended....by inserting...the following new sections: "Sec. 20. (a) The National Bureau of Standards shall—(1) have the mission of developing standards, guidelines, and associated methods and techniques for computer systems; (2) except as described in paragraph (3) of this subsection (relating to security standards), develop uniform standards and guidelines for Federal computer systems....(3) have responsibility within the Federal Government for developing technical, management, physical, and administrative standards and guidelines for the cost-effective security and privacy of sensitive information in Federal computer systems...(4) submit standards and guidelines developed pursuant to...this subsection...to the Secretary of Commerce for promulgation under...the Federal Property and Administrative Services Act of 1949; (5) develop guidelines for use by operators of Federal computer systems that contain sensitive information in training their employees in security awareness and accepted security practice...(6) develop validation procedures for, and evaluate the effectiveness of, standards and guidelines developed pursuant to....this subsection through research and liaison with other government and private agencies. (b) In fulfilling subsection (a) of this section, the National Bureau of Standards is authorized—(1) to assist the private sector, upon request, in using and applying the results of the programs and activities under this section; (2) to make recommendations, as appropriate, to the Administrator of General Services on policies and regulations proposed pursuant to section 111(d) of the Federal Property and Administrative Services Act of 1949; (3) as requested, to provide to operators of Federal computer systems technical assistance in implementing the standards and guidelines promulgated pursuant to section 111(d) of the Federal Property and Administrative Act of 1949; (4) to assist, as appropriate, the Office of Personnel Management in developing regulations pertaining to training, as required by section 5 of the Computer Security Act of 1987; (5) to perform research and to conduct studies, as needed, to determine the nature and extent of the vulnerabilities of, and to devise techniques for the cost-effective security and privacy of sensitive information in Federal computer systems; and (6) to coordinate closely with other agencies and offices....

"SEC. 21. (a) (101 Stat. 1727) There is hereby established a Computer System Security and Privacy Advisory Board within the Department of Commerce.

SEC.4. (101 Stat. 1728) Amendment to Brooks Act. Section 111(d) of the Federal Property and Administrative Services Act of 1949 is amended to read as follows: "(d)(1) The Secretary of Commerce shall, on the basis of standards and guidelines developed by the National Bureau of Standards pursuant to section 20(a) (2) and (3) of the National Bureau of Standards Act, promulgate standards and guidelines pertaining to Federal computer systems, making such standards compulsory and binding to the extent to which the Secretary determines necessary to improve the efficiency of operation or security and privacy of Federal computer systems.....

* * * * *

August 23, 1988, 102 Stat. 1107 (Public Law 100-418—-100th Congress, 2d session) Omnibus Trade and Competitiveness Act of 1988.

Public Law 100-418

AN ACT

To enhance the competitiveness of American industry, and for other purposes.

SUBTITLE B—TECHNOLOGY

PART I—TECHNOLOGY COMPETITIVENESS

SEC. 5101. *15 USC 271 note* SHORT TITLE.
This part may be cited as the "Technology Competitiveness Act".

SUBPART A—NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

SEC.. 5111. FINDINGS AND PURPOSES.

Section 1 of the Act of March 3, 1901 (15 U.S.C. 271) is amended to read as follows:
"FINDINGS AND PURPOSES

"SECTION 1. (a) The Congress finds and declares the following:

"(1) The future well-being of the United States economy depends on a strong manufacturing base and requires continual improvements in manufacturing technology, quality control, and techniques for ensuring product reliability and cost-effectiveness.

"(2) Precise measurements, calibrations, and standards help United States industry and manufacturing concerns compete strongly in world markets.

"(3) Improvements in manufacturing and product technology depend on fundamental scientific and engineering research to develop (A) the precise and accurate measurement methods and measurement standards needed to improve quality and reliability, and (B) new technological processes by which such improved methods may be used in practice to improve manufacturing and to assist industry to transfer important laboratory discoveries into commercial products.

"(4) Scientific progress, public safety, and product compatibility and standardization also depend on the development of precise measurement methods, standards, and related basic technologies.

"(5) The National Bureau of Standards since its establishment has served as the Federal focal point in developing basic measurement standards and related technologies, has taken a lead role in stimulating cooperative work among private industrial organizations in efforts to surmount technological hurdles, and otherwise has been responsible for assisting in the improvement of industrial technology.

"(6) The Federal Government should maintain a national science, engineering, and technology laboratory which provides measurement methods, standards, and associated technologies and which aids United States companies in using new technologies to improve products and manufacturing processes.

"(7) Such national laboratory also should serve industry, trade associations, State technology programs, labor organizations, professional societies, and educational institutions by disseminating information on new basic technologies including automated manufacturing processes.

"(b) It is the purpose of this Act—

"(1) to rename the National Bureau of Standards as the National Institute of Standards and Technology and to modernize and restructure that agency to augment its unique ability to enhance the competitiveness of American industry while maintaining its traditional function as lead national laboratory for providing the measurements, calibrations, and quality assurance techniques which underpin United States commerce, technological progress, improved product reliability and manufacturing processes, and public safety;

"(2) to assist private sector initiatives to capitalize on advanced technology;

"(3) to advance, through cooperative efforts among industries, universities, and government laboratories, promising research and development projects, which can be optimized by the private sector for commercial and industrial applications; and

"(4) to promote shared risks, accelerated development, and pooling of skills which will be necessary to strengthen America's manufacturing industries."

SEC. 5112. ESTABLISHMENT, FUNCTIONS, AND ACTIVITIES.

(a) ESTABLISHMENT, FUNCTIONS, AND ACTIVITIES OF THE INSTITUTE.—Section 2 of the Act of March 3, 1901 (15 U.S.C. 272) is amended to read as follows:

"ESTABLISHMENT, FUNCTIONS, AND ACTIVITIES

"SEC. 2.

(a) There is established within the Department of Commerce a science, engineering, technology, and measurement laboratory to be known as the National Institute of Standards and Technology (hereafter in this Act referred to as the 'Institute').

"(b) The Secretary of Commerce (hereafter in this Act referred to as the 'Secretary') acting through the Director of the Institute (hereafter in this Act referred to as the 'Director') and, if appropriate, through other officials, is authorized to take all actions necessary and appropriate to accomplish the purposes of this Act, including the following functions of the Institute—

"(1) to assist industry in the development of technology and procedures needed to improve quality, to modernize manufacturing processes, to ensure product reliability, manufacturability, functionality, and cost-effectiveness, and to facilitate the more rapid commercialization, especially by small and medium-sized companies throughout the United States, of products based on new scientific discoveries in fields such as automation, electronics, advanced materials, biotechnology, and optical technologies;

"(2) to develop, maintain, and retain custody of the national standards of measurement, and provide the means and methods for making measurements consistent with those standards, including comparing standards used in scientific investigations, engineering, manufacturing, commerce, industry, and educational institutions with the standards adopted or recognized by the Federal Government;

"(3) to enter into contracts, including cooperative research and development arrangements, in furtherance of the purposes of this Act;

"(4) to provide United States industry, Government, and educational institutions with a national clearinghouse of current information, techniques, and advice for the achievement of higher quality and productivity based on current domestic and international scientific and technical development;

"(5) to assist industry in the development of measurements, measurement methods, and basic measurement technology;

"(6) to determine, compile, evaluate, and disseminate physical constants and the properties and performance of conventional and advanced materials when they are important to science, engineering, manufacturing, education, commerce, and industry and are not available with sufficient accuracy elsewhere;

"(7) to develop a fundamental basis and methods for testing materials, mechanisms, structures, equipment, and systems, including those used by the Federal Government;

"(8) to assure the compatibility of United States national measurement standards with those of other nations;

"(9) to cooperate with other departments and agencies of the Federal Government, with industry, with State and local governments, with the governments of other nations and international organizations, and with private organizations in establishing standard practices, codes, specifications, and voluntary consensus standards;

"(10) to advise government and industry on scientific and technical problems; and

"(11) to invent, develop, and (when appropriate) promote transfer to the private sector of measurement devices to serve special national needs.

"(c) In carrying out the functions specified in subsection (b), the Secretary, acting through the Director and, if appropriate, through other appropriate officials, may, among other things—

"(1) construct physical standards;

"(2) test, calibrate, and certify standards and standard measuring apparatus;

"(3) study and improve instruments, measurement methods, and industrial process control and quality assurance techniques;

"(4) cooperate with the States in securing uniformity in weights and measures laws and methods of inspection;

"(5) cooperate with foreign scientific and technical institutions to understand technological developments in other countries better;

"(6) prepare, certify, and sell standard reference materials for use in ensuring the accuracy of chemical analyses and measurements of physical and other properties of materials;

"(7) in furtherance of the purposes of this Act, accept research associates, cash donations, and donated equipment from industry, and also engage with industry in research to develop new basic and generic technologies for traditional and new products and for improved production and manufacturing;

"(8) study and develop fundamental scientific understanding and improved measurement, analysis, synthesis, processing, and fabrication methods for chemical substances and compounds, ferrous and nonferrous metals, and all traditional and advanced materials, including processes of degradation;

"(9) investigate ionizing and nonionizing radiation and radioactive substances, their uses, and ways to protect people, structures, and equipment from their harmful effects;

"(10) determine the atomic and molecular structure of matter, through analysis of spectra and other methods, to provide a basis for predicting chemical and physical structures and reactions and for designing new materials and chemical substances, including biologically active macromolecules;

"(11) perform research on electromagnetic waves, including optical waves, and on properties and performance of electrical, electronic, and electromagnetic devices and systems and their essential materials, develop and maintain related standards, and disseminate standard signals through broadcast and other means;

"(12) develop and test standard interfaces, communication protocols, and data structures for computer and related telecommunications systems;

"(13) study computer systems (as that term is defined in section 20(d) of this Act) and their use to control machinery and processes;

"(14) perform research to develop standards and test methods to advance the effective use of computers and related systems and to protect the information stored, processed, and transmitted by such systems and to provide advice in support of policies affecting Federal computer and related telecommunications systems;

"(15) determine properties of building materials and structural elements, and encourage their standardization and most effective use, including investigation of fire-resisting properties of building materials and conditions under which they may be most efficiently used, and the standardization of types of appliances for fire prevention;

"(16) undertake such research in engineering, pure and applied mathematics, statistics, computer science, materials science, and the physical sciences as may be necessary to carry out and support the functions specified in this section;

"(17) compile, evaluate, publish, and otherwise disseminate general, specific and technical data resulting from the performance of the functions specified in this section or from other sources when such data are important to science, engineering, or industry, or to the general public, and are not available elsewhere;

"(18) collect, create, analyze, and maintain specimens of scientific value;

"(19) operate national user facilities;

"(20) evaluate promising inventions and other novel technical concepts submitted by inventors and small companies and work with other Federal agencies, States, and localities to provide appropriate technical assistance and support for those inventions which are found in the evaluation process to have commercial promise;

"(21) demonstrate the results of the Institute's activities by exhibits or other methods of technology transfer, including the use of scientific or technical personnel of the Institute for part-time or intermittent teaching and training activities at educational institutions of higher learning as part of and incidental to their official duties; and

"(22) undertake such other activities similar to those specified in this subsection as the Director determines appropriate."

(b) OTHER FUNCTIONS OF SECRETARY. —The Secretary of Commerce is authorized to—

(1) conduct research on all of the telecommunications sciences, including wave propagation and reception, the conditions which affect electromagnetic wave propagation and reception, electromagnetic noise and interference, radio system characteristics, operating techniques affecting the use of the electromagnetic spectrum, and methods for improving the use of the electromagnetic spectrum for telecommunications purposes;

(2) prepare and issue predictions of electromagnetic wave propagation conditions and warnings of disturbances in such conditions;

(3) investigate conditions which affect the transmission of radio waves from their source to a receiver and the compilation and distribution of information on such transmission of radio waves as a basis for choice of frequencies to be used in radio operations;

(4) conduct research and analysis in the general field of telecommunications sciences in support of assigned functions and in support of other Government agencies;

(5) investigate nonionizing electromagnetic radiation and its uses, as well as methods and procedures for measuring and assessing electromagnetic environments, for the purpose of developing and coordinating policies and procedures affecting Federal Government use of the electromagnetic spectrum for telecommunications purposes;

(6) compile, evaluate, publish, and otherwise disseminate general scientific and technical data resulting from the performance of the functions specified in this section or from other sources when such data are important to science, engineering, or industry, or to the general public, and are not available elsewhere; and

(7) undertake such other activities similar to those specified in this subsection as the Secretary of Commerce determines appropriate.

(c) DIRECTOR OF INSTITUTE. —(1) Section 5 of the Act of March 3, 1901 (15 U.S.C. 274) is amended to read as follows:

"SEC. 5. The Director shall be appointed by the President, by and with the advice and consent of the Senate. The Director shall have the general supervision of the Institute, its equipment, and the exercise of its functions. The Director shall make an annual report to the Secretary of Commerce. The Director may issue, when necessary, bulletins for public distribution, containing such information as may be of value to the public or facilitate the exercise of the functions of the Institute. The Director shall be compensated at the rate in effect for level IV of the Executive Schedule under section 5315 of title 5, United States Code. Until such time as the Director assumes office under this section, the most recent Director of the National Bureau of Standards shall serve as Director.".

(2) Section 5315 of title 5, United States Code, is amended by striking "National Bureau of Standards" and inserting in lieu thereof "National Institute of Standards and Technology".

(d) ORGANIZATION PLAN. —(1) At least 60 days before its effective date and within 120 days after the date of the enactment of this Act, an initial organization plan for the National Institute of Standards and Technology (hereafter in this part referred to as the "Institute") shall be submitted by the Director of the Institute (hereafter in this part referred to as the "Director") after consultation with the Visiting Committee on Advanced Technology, to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate. Such plan shall—

(A) establish the major operating units of the Institute;

(B) assign each of the activities listed in section 2(c) of the Act of March 3, 1901, and all other functions and activities of the Institute, to at least one of the major operating units established under subparagraph (A);

(C) provide details of a 2-year program for the Institute, including the Advanced Technology Program;

(D) provide details regarding how the Institute will expand and fund the Inventions program in accordance with section 27 of the Act of March 3, 1901; and

(E) make no changes in the Center for Building Technology or the Center for Fire Research.

(2) The Director may revise the organization plan. Any revision of the organization plan submitted under paragraph (1) shall be submitted to the appropriate committees of the House of Representatives and the Senate at least 60 days before the effective date of such revision.

(3) Until the effective date of the organization plan, the major operating units of the Institute shall be the major operating units of the National Bureau of Standards that were in existence on the date of the enactment of this Act and the Advanced Technology Program.

SEC. 5113. REPEAL OF PROVISIONS.
The second paragraph of the material relating to the Bureau of Standards in the first section of the Act of July 16, 1914 (15 U.S.C. 280), the last paragraph of the material relating to Contingent and Miscellaneous Expenses in the first section of the Act of March 4, 1913 (15 U.S.C. 281), and the first section of the Act of May 14, 1930 (15 U.S.C. 282) are repealed.

SEC. 5114. REPORTS TO CONGRESS; STUDIES BY THE NATIONAL ACADEMIES OF ENGINEERING AND SCIENCES.
The Act of March 3, 1901 (15 U.S.C. 271 et seq.) is amended–

(1) by redesignating section 23 as section 31; and

(2) by adding after section 22 the following new sections:

"REPORTS TO CONGRESS

"SEC. 23.

"(a) The Director shall keep the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives fully and currently informed with regard to all of the activities of the Institute.

"(b) The Director shall justify in writing all changes in policies regarding fees for standard reference materials and calibration services occurring after June 30, 1987, including a description of the anticipated impact of any proposed changes on demand for and anticipated revenues from the materials and services. Changes in policy and fees shall not be effective unless and until the Director has submitted the proposed schedule and justification to the Congress and 30 days on which both Houses of Congress are in session have elapsed since such submission, except that the requirement of this sentence shall not apply with respect to adjustments which are based solely on changes in the costs of raw materials or of producing and delivering standard reference materials or calibration services.

"STUDIES BY THE NATIONAL RESEARCH COUNCIL

"SEC. 24. The Director may periodically contract with the National Research Council for advice and studies to assist the Institute to serve United States industry and science. The subjects of such advice and studies may include—

"(1) the competitive position of the United States in key areas of manufacturing and emerging technologies and research activities which would enhance that competitiveness;

"(2) potential activities of the Institute, in cooperation with industry and the States, to assist in the transfer and dissemination of new technologies for manufacturing and quality assurance; and

"(3) identification and assessment of likely barriers to widespread use of advanced manufacturing technology by the United States workforce, including training and other initiatives which could lead to a higher percentage of manufacturing jobs of United States companies being located within the borders of our country."

"SEC. 5115. TECHNICAL AMENDMENTS.

(a) AMENDMENTS TO ORGANIC ACT. —

(1) Except as provided in paragraph (2), the Act of March 3, 1901 (15 U.S.C. 271 et seq.) is amended by striking "National Bureau of Standards", "Bureau" and "bureau" wherever they appear and inserting in lieu thereof "Institute".

(2) Section 31 of such Act, as so redesignated by section 5114(1) of this part, is amended by striking "National Bureau of Standards" and inserting in lieu thereof "National Institute of Standards and Technology".

(b) AMENDMENTS TO STEVENSON-WYDLER TECHNOLOGY INNOVATION ACT OF 1980. —(1) Section 8(b) of the Stevenson-Wydler Technology Innovation Act of 1980, as so redesignated by section 5122 of this part, is amended by striking "Director" and inserting in lieu thereof "Assistant Secretary".

(2) Sections 11(e) and 17(d) and (e) of the Stevenson-Wydler Technology Innovation Act of 1980, as so redesignated by section 5122(a)(1) of this part, are amended—

(A) by striking "National Bureau of Standards" wherever it appears and inserting in lieu thereof "National Institute of Standards and Technology"; and

(B) by striking "Bureau" wherever it appears and inserting in lieu thereof "Institute".

(c) AMENDMENTS TO OTHER LAWS. —References in any other Federal law to the National Bureau of Standards shall be deemed to refer to the National Institute of Standards and Technology

SUBPART B—TECHNOLOGY EXTENSION ACTIVITIES AND CLEARINGHOUSE ON STATE AND LOCAL INITIATIVES

SEC. 5121. TECHNOLOGY EXTENSION ACTIVITIES.

(a) TECHNOLOGY CENTERS AND TECHNICAL ASSISTANCE. —The Act of March 3, 1901, as amended by this part, is further amended by adding after section 24 the following new sections:

"REGIONAL CENTERS FOR THE TRANSFER OF MANUFACTURING TECHNOLOGY

"SEC. 25. (a) The Secretary, through the Director and, if appropriate, through other officials, shall provide assistance for the creation and support of Regional Centers for the Transfer of Manufacturing Technology (hereafter in this Act referred to as the 'Centers'). Such centers shall be affiliated with any United States-based nonprofit institution or organization, or group thereof, that applies for and is awarded financial assistance under this section in accordance with the description published by the Secretary in the Federal Register under subsection (c)(2). Individual awards shall be decided on the basis of merit review. The objective of the Centers is to enhance productivity and technological performance in United States manufacturing through—

"(1) the transfer of manufacturing technology and techniques developed at the Institute to Centers and, through them, to manufacturing companies throughout the United States;

"(2) the participation of individuals from industry, universities, State governments, other Federal agencies, and, when appropriate, the Institute in cooperative technology transfer activities;

"(3) efforts to make new manufacturing technology and processes usable by United States-based small- and medium-sized companies;

"(4) the active dissemination of scientific, engineering, technical, and management information about manufacturing to industrial firms, including small- and medium-sized manufacturing companies; and

"(5) the utilization, when appropriate, of the expertise and capability that exists in Federal laboratories other than the Institute.

"(b) The activities of the Centers shall include—

"(1) the establishment of automated manufacturing systems and other advanced production technologies, based on research by the Institute, for the purpose of demonstrations and technology transfer;

"(2) the active transfer and dissemination of research findings and Center expertise to a wide range of companies and enterprises, particularly small- and medium-sized manufacturers; and

"(3) loans, on a selective, short-term basis, of items of advanced manufacturing equipment to small manufacturing firms with less than 100 employees.

"(c)(1) The Secretary may provide financial support to any Center created under subsection (a) for a period not to exceed six years. The Secretary may not provide to a Center more than 50 percent of the capital and annual operating and maintenance funds required to create and maintain such Center.

"(2) The Secretary shall publish in the Federal Register, within 90 days after the date of the enactment of this section, a draft description of a program for establishing Centers, including—

"(A) a description of the program;

"(B) procedures to be followed by applicants;

"(C) criteria for determining qualified applicants;

"(D) criteria, including those listed under paragraph (4), for choosing recipients of financial assistance under this section from among the qualified applicants; and

"(E) maximum support levels expected to be available to Centers under the program in the fourth through sixth years of assistance under this section.

The Secretary shall publish a final description under this paragraph after the expiration of a 30-day comment period.

"(3) Any nonprofit institution, or group thereof, or consortia of nonprofit institutions, including entities existing on the date of the enactment of this section, may submit to the Secretary an application for financial support under this subsection, in accordance with the procedures established by the Secretary and published in the Federal Register under paragraph (2). In order to receive assistance under this section, an applicant shall provide adequate assurances that it will contribute 50 percent or more of the proposed Center's capital and annual operating and maintenance costs for the first three years and an increasing share for each of the last three years. Each applicant shall also submit a proposal for the allocation of the legal rights associated with any invention which may result from the proposed Center's activities.

"(4) The Secretary shall subject each such application to merit review. In making a decision whether to approve such application and provide financial support under this subsection, the Secretary shall consider at a minimum (A) the merits of the application, particularly those portions of the application regarding technology transfer, training and education, and adaptation of manufacturing technologies to the needs of particular industrial sectors, (B) the quality of service to be provided, (C) geographical diversity and extent of service area, and (D) the percentage of funding and amount of in-kind commitment from other sources.

"(5) Each Center which receives financial assistance under this section shall be evaluated during its third year of operation by an evaluation panel appointed by the Secretary. Each such evaluation panel shall be composed of private experts, none of whom shall be connected with the involved Center, and Federal officials. An official of the Institute shall chair the panel. Each evaluation panel shall measure the involved Center's performance against the objectives specified in this section. The Secretary shall not provide funding for the fourth through the sixth years of such Center's operation unless the evaluation is positive. If the evaluation is positive, the Secretary may provide continued funding through the sixth year at declining levels, which are designed to ensure that the Center no longer needs financial support from the Institute by the seventh year. In no event shall funding for a Center be provided by the Department of Commerce after the sixth year of the operation of a Center.

"(6) The provisions of chapter 18 of title 35, United States Code, shall (to the extent not inconsistent with this section) apply to the promotion of technology from research by Centers under this section.

"(d) There are authorized to be appropriated for the purposes of carrying out this section, a combined total of not to exceed $40,000,000 for fiscal years 1989 and 1990. Such sums shall remain available until expended.

"ASSISTANCE TO STATE TECHNOLOGY PROGRAMS

"SEC. 26.

(a) In addition to the Centers program created under section 25, the Secretary, through the Director and, if appropriate, through other officials, shall provide technical assistance to State technology programs throughout the United States, in order to help those programs help businesses, particularly small- and medium-sized businesses, to enhance their competitiveness through the application of science and technology.

"(b) Such assistance from the Institute to State technology programs shall include, but not be limited to—

"(1) technical information and advice from Institute personnel;

"(2) workshops and seminars for State officials interested in transferring Federal technology to businesses; and

"(3) entering into cooperative agreements when authorized to do so under this or any other Act."

(b) TECHNOLOGY EXTENSION SERVICES. —(1) The Secretary shall conduct a nationwide study of current State technology extension services. The study shall include—

(A) a thorough description of each State program, including its duration, its annual budget, and the number and types of businesses it has aided;

(B) a description of any anticipated expansion of each State program and its associated costs;

(C) an evaluation of the success of the services in transferring technology, modernizing manufacturing processes, and improving the productivity and profitability of businesses;

(D) an assessment of the degree to which State services make use of Federal programs, including the Small Business Innovative Research program and the programs of the Federal Laboratory Consortium, the National Technical Information Service, the National Science Foundation, the Office of Productivity, Technology, and Innovation, and the Small Business Administration;

(E) a survey of what additional Federal information and technical assistance the services could utilize; and

(F) an assessment of how the services could be more effective agents for the transfer of Federal scientific and technical information, including the results and application of Federal and federally funded research.

The Secretary shall submit to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate, at the time of submission of the organization plan for the Institute under section 5112(d)(1), the results of the study and an initial implementation plan for the programs under section 26 of the Act of March 3, 1901, and under this section. The implementation plan shall include methods of providing technical assistance to States and criteria for awarding financial assistance under this section. The Secretary may make use of contractors and experts for any or all of the studies and findings called for in this section.

(2)(A) The Institute shall enter into cooperative agreements with State technology extension services to—

(i) demonstrate methods by which the States can, in cooperation with Federal agencies, increase the use of Federal technology by businesses within their States to improve industrial competitiveness; or

(ii) help businesses in their States take advantage of the services and information offered by the Regional Centers for the Transfer of Manufacturing Technology created under section 25 of the Act of March 3, 1901.

(B) Any State, for itself or for a consortium of States, may submit to the Secretary an application for a cooperative agreement under this subsection, in accordance with procedures established by the Secretary. To qualify for a cooperative agreement under this subsection, a State shall provide adequate assurances that it will increase its spending on technology extension services by an amount at least equal to the amount of Federal assistance.

(C) In evaluating each application, the Secretary shall consider—

(i) the number and types of additional businesses that will be assisted under the cooperative agreement;

(ii) the extent to which the State extension service will demonstrate new methods to increase the use of Federal technology;

(iii) geographic diversity; and

(iv) the ability of the State to maintain the extension service after the cooperative agreement has expired.

(D) States which are party to cooperative agreements under this subsection may provide services directly or may arrange for the provision of any or all of such services by institutions of higher education or other non-profit institutions or organizations.

(3) In carrying out section 26 of the Act of March 3, 1901, and this subsection, the Secretary shall coordinate the activities with the Federal Laboratory Consortium; the National Technical Information Service; the National Science Foundation; the Office of Productivity, Technology, and Innovation; the Small Business Administration; and other appropriate Federal agencies.

(4) There are authorized to be appropriated for the purposes of this subsection $2,000,000 for each of the fiscal years 1989, 1990, and 1991.

(5) Cooperative agreements entered into under paragraph (2) shall terminate no later than September 30, 1991.

(c) FEDERAL TECHNOLOGY TRANSFER ACT OF 1986. —Nothing in sections 25 or 26 of the Act of March 3, 1901, or in subsection (b) of this section shall be construed as limiting the authorities contained in the Federal Technology Transfer Act of 1986 (Public Law 99-502).

(d) NON-ENERGY INVENTIONS PROGRAM. —The Act of March 3, 1901, as amended by this part, is further amended by adding after section 26 the following new section:

"NON-ENERGY INVENTIONS PROGRAM

"SEC. 27. In conjunction with the initial organization of the Institute, the Director shall establish a program for the evaluation of inventions that are not energy-related to complement but not replace the Energy-Related Inventions Program established under section 14 of the Federal Nonnuclear Energy Research and Development Act of 1974 (Public Law 93-577). The Director shall submit an initial implementation plan for this program to accompany the organization plan for the Institute. The implementation plan shall include specific cost estimates, implementation schedules, and mechanisms to help finance the development of technologies the program has determined to have potential. In the preparation of the plan, the Director shall consult with appropriate Federal agencies, including the Small Business Administration and the Department of Energy, State and local government organizations, university officials, and private sector organizations in order to obtain advice on how those agencies and organizations might cooperate with the expansion of this program of the Institute."

"SEC. 5122. CLEARINGHOUSE ON STATE AND LOCAL INITIATIVES.

(a) CLEARINGHOUSE. —The Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3701 et seq.) is amended—

(1) by redesignating sections 6 through 19 as sections 7 through 20, respectively; and

(2) by inserting after section 5 the following new section:

"SEC. 6. CLEARINGHOUSE FOR STATE AND LOCAL INITIATIVES ON PRODUCTIVITY, TECHNOLOGY, AND INNOVATION.

"(a) ESTABLISHMENT. —There is established within the Office of Productivity, Technology, and Innovation a Clearinghouse for State and Local Initiatives on Productivity, Technology, and Innovation. The Clearinghouse shall serve as a central repository of information on initiatives by State and local governments to enhance the competitiveness of American business through the stimulation of productivity, technology, and innovation and Federal efforts to assist State and local governments to enhance competitiveness.

"(b) RESPONSIBILITIES. —The Clearinghouse may—

"(1) establish relationships with State and local governments, and regional and multistate organizations of such governments, which carry out such initiatives;

"(2) collect information on the nature, extent, and effects of such initiatives, particularly information useful to the Congress, Federal agencies, State and local governments, regional and multistate organizations of such governments, businesses, and the public throughout the United States;

"(3) disseminate information collected under paragraph (2) through reports, directories, handbooks, conferences, and seminars;

"(4) provide technical assistance and advice to such governments with respect to such initiatives, including assistance in determining sources of assistance from Federal agencies which may be available to support such initiatives;

"(5) study ways in which Federal agencies, including Federal laboratories, are able to use their existing policies and programs to assist State and local governments, and regional and multistate organizations of such governments, to enhance the competitiveness of American business;

"(6) make periodic recommendations to the Secretary, and to other Federal agencies upon their request, concerning modifications in Federal policies and programs which would improve Federal assistance to State and local technology and business assistance programs;

"(7) develop methodologies to evaluate State and local programs, and, when requested, advise State and local governments, and regional and multistate organizations of such governments, as to which programs are most effective in enhancing the competitiveness of American business through the stimulation of productivity, technology, and innovation; and

"(8) make use of, and disseminate, the nationwide study of State industrial extension programs conducted by the Secretary.

"(c) CONTRACTS. —In carrying out subsection (b), the Secretary may enter into contracts for the purpose of collecting information on the nature, extent, and effects of initiatives.

"(d) TRIENNIAL REPORT. —The Secretary shall prepare and transmit to the Congress once each 3 years a report on initiatives by State and local governments to enhance the competitiveness of American businesses through the stimulation of productivity, technology, and innovation. The report shall include recommendations to the President, the Congress, and to Federal agencies on the appropriate Federal role in stimulating State and local efforts in this area. The first of these reports shall be transmitted to the Congress before January 1, 1989.".

(b) DEFINITION. —Section 4 of such Act is amended by adding at the end thereof the following new paragraph:

"(13) 'Clearinghouse' means the Clearinghouse for State and Local Initiatives on Productivity, Technology, and Innovation established by section 6."

(c) CONFORMING AMENDMENT. —Section 10(d) of such Act, as so redesignated by section 5122(a)(1) of this part, is amended by striking "6, 8, 10, 14, 16, or 17" and inserting in lieu thereof "7, 9, 11, 15, 17, or 18".

SUBPART C—ADVANCED TECHNOLOGY PROGRAM

SEC. 5131. ADVANCED TECHNOLOGY.

(a) ADVANCED TECHNOLOGY PROGRAM. —The Act of March 3, 1901, as amended by this part, is further amended by adding after section 27 the following new section:

"ADVANCED TECHNOLOGY PROGRAM

"SEC. 28.

(a) There is established in the Institute an Advanced Technology Program (hereafter in this Act referred to as the 'Program') for the purpose of assisting United States businesses in creating and applying the generic technology and research results necessary to—

"(1) commercialize significant new scientific discoveries and technologies rapidly; and

"(2) refine manufacturing technologies.

The Secretary, acting through the Director, shall assure that the Program focuses on improving the competitive position of the United States and its businesses, gives preference to discoveries and to technologies that have great economic potential, and avoids providing undue advantage to specific companies.

"(b) Under the Program established in subsection (a), and consistent with the mission and policies of the Institute, the Secretary, acting through the Director, and subject to subsections (c) and (d), may—

"(1) aid United States joint research and development ventures (hereafter in this section referred to as 'joint ventures') (which may also include universities and independent research organizations), including those involving collaborative technology demonstration projects which develop and test prototype equipment and processes, through—

"(A) provision of organizational and technical advice; and

"(B) participation in such joint ventures, if the Secretary, acting through the Director, determines participation to be appropriate, which may include (i) partial start-up funding, (ii) provision of a minority share of the cost of such joint ventures for up to 5 years, and (iii) making available equipment, facilities, and personnel, provided that emphasis is placed on areas where the Institute has scientific or technological expertise, on solving generic problems of specific industries, and on making those industries more competitive in world markets;

"(2) enter into contracts and cooperative agreements with United States businesses, especially small businesses, and with independent research organizations, provided that emphasis is placed on applying the Institute's research, research techniques, and expertise to those organizations' research programs;

"(3) involve the Federal laboratories in the Program, where appropriate, using among other authorities the cooperative research and development agreements provided for under section 12 of the Stevenson-Wydler Technology Innovation Act of 1980; and

"(4) carry out, in a manner consistent with the provisions of this section, such other cooperative research activities with joint ventures as may be authorized by law or assigned to the Program by the Secretary.

"(c) The Secretary, acting through the Director, is authorized to take all actions necessary and appropriate to establish and operate the Program, including—

"(1) publishing in the Federal Register draft criteria and, no later than six months after the date of the enactment of this section, following a public comment period, final criteria, for the selection of recipients of assistance under subsection (b) (1) and (2);

"(2) monitoring how technologies developed in its research program are used, and reporting annually to the Congress on the extent of any overseas transfer of these technologies;

"(3) establishing procedures regarding financial reporting and auditing to ensure that contracts and awards are used for the purposes specified in this section, are in accordance with sound accounting practices, and are not funding existing or planned research programs that would be conducted in the same time period in the absence of financial assistance under the Program;

"(4) assuring that the advice of the Committee established under section 10 is considered routinely in carrying out the responsibilities of the Institute; and

"(5) providing for appropriate dissemination of Program research results.

"(d) When entering into contracts or making awards under subsection (b), the following shall apply:

"(1) No contract or award may be made until the research project in question has been subject to a merit review, and has, in the opinion of the reviewers appointed by the Director and the Secretary, acting through the Director, been shown to have scientific and technical merit.

"(2) In the case of joint ventures, the Program shall not make an award unless, in the judgment of the Secretary, acting through the Director, Federal aid is needed if the industry in question is to form a joint venture quickly.

"(3) No Federal contract or cooperative agreement under subsection (b)(2) shall exceed $2,000,000 over 3 years, or be for more than 3 years unless a full and complete explanation of such proposed award, including reasons for exceeding these limits, is submitted in writing by the Secretary to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives. The proposed contract or cooperative agreement may be executed only after 30 calendar days on which both Houses of Congress are in session have elapsed since such submission. Federal funds made available under subsection (b)(2) shall be used only for direct costs and not for indirect costs, profits, or management fees of the contractor.

"(4) In determining whether to make an award to a particular joint venture, the Program shall consider whether the members of the joint venture have made provisions for the appropriate participation of small United States businesses in such joint venture.

"(5) Section 552 of title 5, United States Code, shall not apply to the following information obtained by the Federal Government on a confidential basis in connection with the activities of any business or any joint venture receiving funding under the Program—

"(A) information on the business operation of any member of the business or joint venture; and

"(B) trade secrets possessed by any business or any member of the joint venture.

"(6) Intellectual property owned and developed by any business or joint venture receiving funding or by any member of such a joint venture may not be disclosed by any officer or employee of the Federal Government except in accordance with a written agreement between the owner or developer and the Program.

"(7) The Federal Government shall be entitled to a share of the licensing fees and royalty payments made to and retained by any business or joint venture to which it contributes under this section in an amount proportional to the Federal share of the costs incurred by the business or joint venture as determined by independent audit.

"(8) If a business or joint venture fails before the completion of the period for which a contract or award has been made, after all allowable costs have been paid and appropriate audits conducted, the unspent balance of the Federal funds shall be returned by the recipient to the Program.

"(9) Upon dissolution of any joint venture or at the time otherwise agreed upon, the Federal Government shall be entitled to a share of the residual assets of the joint venture proportional to the Federal share of the costs of the joint venture as determined by independent audit.

"(e) As used in this section, the term 'joint research and development venture' has the meaning given to such term in section 2(a)(6) of the National Cooperative Research Act of 1984 (15 U.S.C. 4301(a)(6))."

(b) VISITING COMMITTEE ON ADVANCED TECHNOLOGY. —Section 10 of the Act of March 3, 1901, is amended to read as follows:

"VISITING COMMITTEE ON ADVANCED TECHNOLOGY

"SEC. 10.

(a) There is established within the Institute a Visiting Committee on Advanced Technology (hereafter in this Act referred to as the 'Committee'). The Committee shall consist of nine members appointed by the Director, at least five of whom shall be from United States industry. The Director shall appoint as original members of the Committee any final members of the National Bureau of Standards Visiting Committee who wish to serve in such capacity. In addition to any powers and functions otherwise granted to it by this Act, the Committee shall review and make recommendations regarding general policy for the Institute, its organization, its budget, and its programs within the framework of applicable national policies as set forth by the President and the Congress.

"(b) The persons appointed as members of the Committee—

"(1) shall be eminent in fields such as business, research, new product development, engineering, labor, education, management consulting, environment, and international relations;

"(2) shall be selected solely on the basis of established records of distinguished service;.

"(3) shall not be employees of the Federal Government; and

"(4) shall be so selected as to provide representation of a cross-section of the traditional and emerging United States industries.

The Director is requested, in making appointments of persons as members of the Committee, to give due consideration to any recommendations which may be submitted to the Director by the national academies, professional societies, business associations, labor associations, and other appropriate organizations.

"(c)(1) The term of office of each member of the Committee, other than the original members, shall be 3 years; except that any member appointed to fill a vacancy occurring prior to the expiration of the term for which his predecessor was appointed shall be appointed for the remainder of such term. Any person who has completed two consecutive full terms of service on the Committee shall thereafter be ineligible for appointment during the one-year period following the expiration of the second such term.

"(2) The original members of the Committee shall be elected to three classes of three members each; one class shall have a term of one year, one a term of two years, and the other a term of three years.

"(d) The Committee shall meet at least quarterly at the call of the Chairman or whenever one-third of the members so request in writing. A majority of the members of the Committee not having a conflict of interest in the matter being considered by the Committee shall constitute a quorum. Each member shall be given appropriate notice, whenever possible, not less than 15 days prior to any meeting, of the call of such meeting.

"(e) The Committee shall have an executive committee, and may delegate to it or to the Secretary such of the powers and functions granted to the Committee by this Act as it deems appropriate. The Committee is authorized to appoint from among its members such other committees as it deems necessary, and to assign to committees so appointed such survey and advisory functions as the Committee deems appropriate to assist it in exercising its powers and functions under this Act.

"(f) The election of the Chairman and Vice Chairman of the Committee shall take place at each annual meeting occurring in an even-numbered year. The Vice Chairman shall perform the duties of the Chairman in his absence. In case a vacancy occurs in the chairmanship or vice chairmanship, the Committee shall elect a member to fill such vacancy.

"(g) The Committee may, with the concurrence of a majority of its members, permit the appointment of a staff consisting of not more than four professional staff members and such clerical staff members as may be necessary. Such staff shall be appointed by the Director, after consultation with the Chairman of the Committee, and assigned at the direction of the Committee. The professional members of such staff may be appointed without regard to the provisions of title 5, United States Code, governing appointments in the competitive service and the provisions of chapter 51 of title 5 of such Code relating to classification, and compensated at a rate not exceeding the appropriate rate provided for individuals in grade GS18 of the General Schedule under section 5332 of title 5 of such Code, as may be necessary to provide for the performance of such duties as may be prescribed by the Committee in connection with the exercise of its powers and functions under this Act.

"(h)(1) The Committee shall render an annual report to the Secretary for submission to the Congress on or before January 31 in each year. Such report shall deal essentially, though not necessarily exclusively, with policy issues or matters which affect the Institute, including the Program established under section 28, or with which the Committee in its official role as the private sector policy advisor of the Institute is concerned. Each such report shall identify areas of research and research techniques of the Institute of potential importance to the long-term competitiveness of United States industry, in which the Institute possesses special competence, which could be used to assist United States enterprises and United States industrial joint research and development ventures.

"(2) The Committee shall render to the Secretary and the Congress such additional reports on specific policy matters as it deems appropriate."

(c) NATIONAL ACADEMIES OF SCIENCES AND ENGINEERING STUDY OF GOVERNMENT-INDUSTRY COOPERATION IN CIVILIAN TECHNOLOGY.—

(1) Within 90 days after the date of enactment of this Act, the Secretary of Commerce shall enter into contracts with the National Academies of Sciences and Engineering for a thorough review of the various types of arrangements under which the private sector in the United States and the Federal Government cooperate in civilian research and technology transfer, including activities to create or apply generic, nonproprietary technologies. The purpose of the review is to provide the Secretary and Congress with objective information regarding the uses, strengths, and limitations of the various types of cooperative technology arrangements that have been used in the United States. The review is to provide both an analysis of the ways

in which these arrangements can help improve the technological performance and international competitiveness of United States industry, and also to provide the Academies' recommendations regarding ways to improve the effectiveness and efficiency of these types of cooperative arrangements. A special emphasis shall be placed on discussions of these subjects among industry leaders, labor leaders, and officials of the executive branch and Congress. The Secretary is authorized to seek and accept funding for this study from both Federal agencies and private industry.

(2) The members of the review panel shall be drawn from among industry and labor leaders, entrepreneurs, former government officials with great experience in civilian research and technology, and scientific and technical experts, including experts with experience with Federal laboratories.

(3) The review shall analyze the strengths and weaknesses of different types of Federal-industry cooperative arrangements in civilian technology, including but not limited to—

(A) Federal programs which provide technical services and information to United States companies;

(B) cooperation between Federal laboratories and United States companies, including activities under the Technology Share Program created by Executive order 12591;

(C) Federal research and technology transfer arrangements with selected business sectors;

(D) Federal encouragement of, and assistance to, private joint research and development ventures; and

(E) such other mechanisms of Federal-industry cooperation as may be identified by the Secretary.

(4) A report based on the findings and recommendations of the review panel shall be submitted to the Secretary, the President, and Congress within 18 months after the Secretary signs the contracts with the National Academies of Sciences and Engineering.

SUBPART D—TECHNOLOGY REVIEWS

SEC. 5141. REPORT OF PRESIDENT.

The President shall, at the time of submission of the budget request for fiscal year 1990 to Congress, also submit to the Congress a report on—

(1) the President's policies and budget proposals regarding Federal research in semiconductors and semiconductor manufacturing technology, including a discussion of the respective roles of the various Federal departments and agencies in such research;

(2) the President's policies and budget proposals regarding Federal research and acquisition policies for fiber optics and optical-electronic technologies generally;

(3) the President's policies and budget proposals, identified by agency, regarding superconducting materials, including descriptions of research priorities, the scientific and technical barriers to commercialization which such research is designed to overcome, steps taken to ensure coordination among Federal agencies conducting research on superconducting materials, and steps taken to consult with private United States industry and to ensure that no unnecessary duplication of research exists and that all important scientific and technical barriers to the commercialization of superconducting materials will be addressed; and

(4) the President's policies and budget proposals, identified by agency, regarding Federal research to assist United States industry to develop and apply advanced manufacturing technologies for the production of durable and nondurable goods.

SEC. 5142. SEMICONDUCTOR RESEARCH AND DEVELOPMENT.

(a) SHORT TITLE. —This section may be cited as the "National Advisory Committee on Semiconductor Research and Development Act of 1988".

(b) FINDINGS AND PURPOSES. —(1) The Congress finds and declares that—

(A) semiconductor technology is playing an ever-increasing role in United States industrial and commercial products and processes, making secure domestic sources of state-of-the-art semiconductors highly desirable;

(B) modern weapons systems are highly dependent on leading edge semiconductor devices, and it is counter to the national security interest to be heavily dependent upon foreign sources for this technology;

(C) governmental responsibilities related to the semiconductor industry are divided among many Federal departments and agencies; and

(D) joint industry-government consideration of semiconductor industry problems is needed at this time.

(2) The purposes of this section are—

(A) to establish the National Advisory Committee on Semiconductors; and

(B) to assign to such Committee the responsibility for devising and promulgating a national semiconductor strategy, including research and development, the implementation of which will assure the continued leadership of the United States in semiconductor technology.

(c) CREATION OF COMMITTEE. —There is hereby created in the executive branch of the Government an independent advisory body to be known as the National Advisory Committee on Semiconductors (hereafter in this section referred to as the "Committee").

(d) FUNCTIONS. —(1) The Committee shall—

(A) collect and analyze information on the needs and capabilities of industry, the Federal Government, and the scientific and research communities related to semiconductor technology;

(B) identify the components of a successful national semiconductor strategy in accordance with subsection (b)(2)(B);

(C) analyze options, establish priorities, and recommend roles for participants in the national strategy;

(D) assess the roles for government and national laboratories and other laboratories supported largely for government purposes in contributing to the semiconductor technology base of the Nation, as well as to access the effective use of the resources of United States private industry, United States universities, and private-public research and development efforts; and

(E) provide results and recommendations to agencies of the Federal Government involved in legislative, policymaking, administrative, management, planning, and technology activities that affect or are part of a national semiconductor strategy, and to the industry and other nongovernmental groups or organizations affected by or contributing to that strategy.

(2) In fulfilling this responsibility, the Committee shall—

(A) monitor the competitiveness of the United States semiconductor technology base;

(B) determine technical areas where United States semiconductor technology is deficient relative to international competition;

(C) identify new or emerging semiconductor technologies that will impact the national defense or United States competitiveness or both;

(D) develop research and development strategies, tactics, and plans whose execution will assure United States semiconductor competitiveness; and

(E) recommend appropriate actions that support the national semiconductor strategy.

(e) MEMBERSHIP AND PROCEDURES. —

(1) (A) The Committee shall be composed of 13 members, 7 of whom shall constitute a quorum.

(B) The Secretary of Defense, the Secretary of Commerce, the Secretary of Energy, the Director of the office of Science and Technology Policy, and the Director of the National Science Foundation, or their designees, shall serve as members of the Committee.

(C) The President, acting through the Director of the office of Science and Technology Policy, shall appoint, as additional members of the Committee, 4 members from outside the Federal Government who are eminent in the semiconductor industry, and 4 members from outside the Federal Government who are eminent in the fields of technology, defense, and economic development.

(D) One of the members appointed under subparagraph (C), as designated by the President at the time of appointment, shall be chairman of the Committee.

(2) Funding and administrative support for the Committee shall be provided to the office of Science and Technology Policy through an arrangement with an appropriate agency or organization designated by the Committee, in accordance with a memorandum of understanding entered into between them.

(3) Members of the Committee, other than full-time employees of the Federal Government, while attending meetings of the Committee or otherwise performing duties at the request of the Chairman while away from their homes or regular places of business, shall be allowed travel expenses in accordance with subchapter I of chapter 57 of title 5, United States Code.

(4) The Chairman shall call the first meeting of the Committee not later than 90 days after the date of the enactment of this Act.

(5) At the close of each fiscal year the Committee shall submit to the President and the Congress a report on its activities conducted during such year and its planned activities for the coming year, including specific findings and recommendations with respect to the national semiconductor strategy devised and promulgated under subsection (b)(2)(B). The first report shall include an analysis of those technical areas, including man-

ufacturing, which are of importance to the United States semiconductor industry, and shall make specific recommendations regarding the appropriate Federal role in correcting any deficiencies identified by the analysis. Each report shall include an estimate of the length of time the Committee must continue before the achievement of its purposes and the issuance of its final report.

(f) AUTHORIZATION OF APPROPRIATIONS. —There are authorized to be appropriated to carry out the purposes of this section such sums as may be necessary for the fiscal years 1988, 1989, and 1990.

SEC. 5143. REVIEW OF RESEARCH AND DEVELOPMENT PRIORITIES IN SUPERCONDUCTORS.

(a) NATIONAL COMMISSION ON SUPERCONDUCTIVITY. —The President shall appoint a National Commission on Superconductivity to review all major policy issues regarding United States applications of recent research advances in superconductors in order to assist the Congress in devising a national strategy, including research and development priorities, the development of which will assure United States leadership in the development and application of superconducting technologies.

(b) MEMBERSHIP. —The membership of the National Commission on Superconductivity shall include representatives of—

(1) the National Critical Materials Council, the National Academy of Sciences, the National Academy of Engineering, the National Science Foundation, the National Aeronautics and Space Administration, the Department of Energy, the Department of Justice, the Department of Commerce (including the National Institute of Standards and Technology), the Department of Transportation, the Department of the Treasury, and the Department of Defense;

(2) organizations whose membership is comprised of physicists, engineers, chemical scientists, or material scientists; and

(3) industries, universities, and national laboratories engaged in superconductivity research.

(c) CHAIRMAN. —A representative of the private sector shall be designated as chairman of the Commission.

(d) COORDINATION. —The National Critical Materials Council shall be the coordinating body of the National Commission on Superconductivity and shall provide staff support for the Commission.

(e) REPORT. —Within 6 months after the date of the enactment of this Act, the National Commission on Superconductivity shall submit a report to the President and the Congress with recommendations regarding methods of enhancing the research, development, and implementation of improved superconductor technologies in all major applications.

(f) SCOPE OF REVIEW. —In preparing the report required by subsection (e), the Commission shall consider addressing, but need not limit, its review to—

(1) the state of United States competitiveness in the development of improved superconductors;

(2) methods to improve and coordinate the collection and dissemination of research data relating to superconductivity;

(3) methods to improve and coordinate funding of research and development of improved superconductors;

(4) methods to improve and coordinate the development of viable commercial and military applications of improved superconductors;

(5) foreign government activities designed to promote research, development, and commercial application of improved superconductors;

(6) the need to provide increased Federal funding of research and development of improved superconductors;

(7) the impact on the United States national security if the United States must rely on foreign producers of superconductors;

(8) the benefit, if any, of granting private companies partial exemptions from United States antitrust laws to allow them to coordinate research, development, and products containing improved superconductors;

(9) options for providing income tax incentives for encouraging research, development, and production in the United States of products containing improved superconductors; and

(10) methods to strengthen domestic patent and trademark laws to ensure that qualified superconductivity discoveries receive the fullest protection from infringement.

(g) SUNSET. —The Commission shall disband within a year of its establishment. Thereafter the National Critical Materials Council may review and update the report required by subsection (e) and make further recommendations as it deems appropriate.

SUBPART E—AUTHORIZATION OF APPROPRIATIONS

SEC. 5151. AUTHORIZATION OF APPROPRIATIONS FOR TECHNOLOGY ACTIVITIES.

(a) AUTHORIZATION OF APPROPRIATIONS. —There are authorized to be appropriated for fiscal year 1988 to the Secretary of Commerce to carry out activities performed by the Institute the sums set forth in the following line items:

(1) Measurement Research and Technology: $41,939,000.

(2) Engineering Measurements and Manufacturing: $40,287,000.

(3) Materials Science and Engineering: $23,521,000.

(4) Computer Science and Technology: $7,941,000.

(5) Research Support Activities: $19,595,000.

(6) Cold Neutron Source Facility: $6,500,000 (for a total authorization of $13,000,000).

(7) Programs established under sections 25, 26, and 27 of the Act of March 3, 1901 and section 5121 of this part: $5,000,000.

(b) LIMITATIONS. —Notwithstanding any other provision of this or any other Act—

(1) of the total of the amounts authorized under subsection (a), $2,000,000 is authorized only for steel technology;

(2) of the amount authorized under paragraph (1) of subsection (a) of this section, $3,550,000 is authorized only for the purpose of research in process and quality control;

(3) of the amount authorized under paragraph (2) of subsection (a) of this section, $3,710,000 is authorized only for the Center for Building Technology, $5,662,000 is authorized only for the Center for Fire Research, and the two Centers shall not be merged;

(4) of the amount authorized under paragraph (3) of subsection (a) of this section, $1,500,000 is authorized only for the purpose of research to improve high-performance composites; and

(5) of the amount authorized under paragraph (5) of subsection (a) of this section, $7,371,000 is authorized only for technical competence fund projects in new areas of high technical importance, and $1,091,000 is authorized only for the Postdoctoral Research Associates Program and related new personnel.

(c) TRANSFER. —

(1) Funds may be transferred among the line items listed in subsection (a) of this section so long as the net funds transferred to or from any line item do not exceed 10 percent of the amount authorized for that line item in such subsection and the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives are notified in advance of any such transfer.

(2) In addition, the Secretary of Commerce may propose transfers to or from any line item exceeding 10 percent of the amount authorized for the line item in subsection (a) of this section, but a full and complete explanation of any such proposed transfer and the reason for such transfer must be transmitted in writing to the President of the Senate, the Speaker of the House of Representatives, and the appropriate authorizing committees of the Senate and House of Representatives. The proposed transfer may be made only when 30 calendar days have passed after the transmission of such written explanation.

(d) COLD NEUTRON SOURCE FACILITY. —In addition to any sums otherwise authorized by this part, there are authorized to be appropriated to the Secretary of Commerce for fiscal years 1988, 1989, and 1990 such sums as were authorized but not appropriated for the Cold Neutron Source Facility for fiscal year 1987. Furthermore, the Secretary may accept contributions for funds, to remain available until expended, for the design, construction, and equipment of the Cold Neutron Source Facility, notwithstanding the limitations of section 14 of the Act of March 3, 1901 (15 U.S.C. 278d).

(e) EMPLOYEE BENEFIT ADJUSTMENTS. —In addition to any sums otherwise authorized by this part, there are authorized to be appropriated to the Secretary of Commerce for fiscal year 1988 such additional sums as may be necessary to make any adjustments in salary, pay, retirement, and other employee benefits which may be provided for by law.

(f) AVAILABILITY. —Appropriations made under the authority provided in this section shall remain available for obligation, for expenditure, or for obligations and expenditure for periods specified in the Acts making such appropriations.

SEC. 5152. STEVENSON-WYDLER ACT AUTHORIZATIONS.

Section 19 (a) and (b) of the Stevenson-Wydler Technology Innovation Act of 1980, as so redesignated by section 5122(a)(1) of this part, is amended to read as follows:

"(a)(1) There is authorized to be appropriated to the Secretary for the purposes of carrying out sections 5, 11(g), and 16 of this Act not to exceed $3,400,000 for the fiscal year ending September 30, 1988.

"(2) of the amount authorized under paragraph (1) of this subsection, $2,400,000 is authorized only for the office of Productivity, Technology, and Innovation; $500,000 is authorized only for the purpose of carrying out the requirements of the Japanese technical literature program established under section 5(d) of this act; and $500,000 is authorized only for the patent licensing activities of the National Technical Information Service.

"(b) In addition to the authorization of appropriations provided under subsection (a) of this section, there is authorized to be appropriated to the Secretary for the purposes of carrying out section 6 of this Act not to exceed $500,000 for the fiscal year ending September 30, 1988, $1,000,000 for the fiscal year ending September 30, 1989, and $1,500,000 for the fiscal year ending September 30, 1990.".

SUBPART F—MISCELLANEOUS TECHNOLOGY AND COMMERCE PROVISIONS

SEC. 5161. SAVINGS PROVISION AND USER FEES.

The Act of March 3, 1901 (15 U.S.C. 271 et seq.), as amended by this part, is further amended by adding after section 28 the following new sections:

"SAVINGS PROVISION

"SEC. 29.

All rules and regulations, determinations, standards, contracts, certifications, authorizations, delegations, results and findings of investigations, or other actions duly issued, made, or taken by or pursuant to this Act, or under the authority of any other statutes which resulted in the assignment of functions or activities to the Secretary, the Department, the Director, or the Institute, as are in effect immediately before the date of enactment of this section, and not suspended by the Secretary, the Director, the Institute or the courts, shall continue in full force and effect after the date of enactment of this section until modified or rescinded.

"USER FEES

"SEC. 30.

The Institute shall not implement a policy of charging fees with respect to the use of Institute research facilities by research associates in the absence of express statutory authority to charge such fees."

SEC. 5162. MISCELLANEOUS AMENDMENTS TO THE STEVENSON-WYDLER ACT.

(a) INVENTION MANAGEMENT SERVICES. —The first sentence of section 14(a)(4) of the Stevenson-Wydler Technology Innovation Act of 1980, as so redesignated by section 5122(a)(1) of this part (15 U.S.C. 3710c) is amended by striking out "shall" and inserting in lieu thereof "may", and by striking out "such invention performed at the request of the other agency or laboratory" and inserting in lieu thereof "any invention of the other agency".

(b) FEDERAL LABORATORY CONSORTIUM. —Section 11(e)(7)(A) of the Stevenson-Wydler Technology Innovation act of 1980, as so redesignated by section 5122(a)(1) of this part (15 U.S.C. 3710) is amended by striking out "0.005 percent of that portion of the research and development budget of each Federal agency that is to be utilized by" and inserting in lieu thereof "0.008 percent of the budget of each Federal agency from any Federal source, including related overhead, that is to be utilized by or on behalf of".

SEC. 5163. MISCELLANEOUS TECHNOLOGY AND COMMERCE PROVISIONS.

(a) ASSESSMENT OF EMERGING TECHNOLOGIES. —The Board of Assessment of the National Institute of Standards and Technology shall include, as part of its annual review, an assessment of emerging technologies which are expected to require research in metrology to keep the Institute abreast of its mission, including process and quality control, engineering databases, advanced materials, electronics and fiber optics, bioprocess engineering, and advanced computing concepts. Such review shall include estimates of the cost of the required effort, required staffing levels, appropriate interaction with industry, including technology transfer, and the period over which the research will be required.

(b) SMALL BUSINESS PLAN. —The Director of the National Institute of Standards and Technology shall prepare a plan detailing the manner in which the Institute will make small businesses more aware of the Institute's activities and research, and the manner in which the Institute will seek to increase the application by small businesses of the Institute's research, particularly in manufacturing. The plan shall be submitted to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives not later than 120 days after the date of the enactment of this act.

(c) NATIONAL TECHNICAL INFORMATION SERVICE. —(1) Section 11 of the Stevenson-Wydler Technology Innovation Act of 1980, as so redesignated by section 5122(a)(1) of this part, is amended by inserting at the end the following new subsection:

"(h) None of the activities or functions of the National Technical Information Service which are not performed by contractors as of September 30, 1987, shall be contracted out or otherwise transferred from the Federal Government unless such transfer is expressly authorized by statute, or unless the value of all work performed under the contract and related contracts in each fiscal year does not exceed $250,000."

(2) The Secretary of Commerce shall report the Secretary's recommendations for improvements in the National Technical Information Service (including methods for automating document distribution and inventory control), and any statutory changes required to make such improvements, to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives by January 31, 1989.

(3) Section 11(d) of the Stevenson-Wydler Technology Innovation Act of 1980, as so redesignated by section 5122(a)(1) of this part, is amended—

(A) by striking "and" at the end of paragraph (4);

(B) by striking the period at the end of paragraph (5) and inserting in lieu thereof "; and"; and

(C) by adding at the end thereof the following new paragraph:

"(6) maintain a permanent archival repository and clearinghouse for the collection and dissemination of nonclassified scientific, technical, and engineering information."

(d) FELLOWSHIP PROGRAM. —There is established within the Department of Commerce a Commerce, Science, and Technology Fellowship Program with the stated purpose of providing a select group of employees of the executive branch of the Government with the opportunity of learning how the legislative branch and other parts of the executive branch function through work experiences of up to one year. The Secretary of Commerce shall report to the Congress within six months after the date of enactment of this Act on the Department of Commerce's plans for implementing such Program by March 31, 1989.

SEC. 5164. METRIC USAGE.

(a) FINDINGS. —Section 2 of the Metric Conversion Act of 1975 is amended by adding at the end thereof the following new paragraphs:

"(3) World trade is increasingly geared towards the metric system of measurement.

"(4) Industry in the United States is often at a competitive disadvantage when dealing in international markets because of its nonstandard measurement system, and is sometimes excluded when it is unable to deliver goods which are measured in metric terms.

"(5) The inherent simplicity of the metric system of measurement and standardization of weights and measures has led to major cost savings in certain industries which have converted to that system.

"(6) The Federal Government has a responsibility to develop procedures and techniques to assist industry, especially small business, as it voluntarily converts to the metric system of measurement.

"(7) The metric system of measurement can provide substantial advantages to the Federal Government in its own operations."

(b) POLICY. —Section 3 of the Metric Conversion Act of 1975 is amended to read as follows:

"SEC. 3. It is therefore the declared policy of the United States—

"(1) to designate the metric system of measurement as the preferred system of weights and measures for United States trade and commerce;

"(2) to require that each Federal agency, by a date certain and to the extent economically feasible by the end of the fiscal year 1992, use the metric system of measurement in its procurements, grants, and other business-related activities, except to the extent that such use is impractical or is likely to cause significant inefficiencies or loss of markets to United States firms, such as when foreign competitors are producing competing products in non-metric units;

"(3) to seek out ways to increase understanding of the metric system of measurement through educational information and guidance and in Government publications; and

"(4) to permit the continued use of traditional systems of weights and measures in nonbusiness activities."

(c) IMPLEMENTATION. —The Metric Conversion Act of 1975 is further amended by redesignating section 12 as section 13, and by inserting after section 11 the following new section:

"SEC. 12.

(a) As soon as possible after the date of the enactment of this section, each agency of the Federal Government shall establish guidelines to carry out the policy set forth in section 3 (with particular emphasis upon the policy set forth in paragraph (2) of that section), and as part of its annual budget submission for each fiscal year beginning after such date shall report to the Congress on the actions which it has taken during the previous fiscal year, as well as the actions which it plans for the fiscal year involved, to implement fully the metric system of measurement in accordance with that policy. Such reporting shall cease for an agency in the fiscal year after it has fully implemented its efforts under section 3(2). As used in this section, the term 'agency of the Federal Government' means an Executive agency or military department as those terms as defined in chapter 1 of title 5, United States Code.

"(b) At the end of the fiscal year 1992, the Comptroller General shall review the implementation of this Act, and upon completion of such review shall report his findings to the Congress along with any legislative recommendations he may have."

* * * * *

October 24, 1988, 102 Stat. 2589 (Public Law 100-519—-100th Congress, 2d session) National Institute of Standards and Technology Authorization Act for Fiscal Year 1989.

Public Law 100-519

AN ACT

To authorize appropriations to the Secretary of Commerce for the programs of the National Bureau of Standards for fiscal year 1989, and for other purposes.

TITLE I—NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY AUTHORIZATION

SECTION 101. SHORT TITLE.

This title may be cited as the "National Institute of Standards and Technology Authorization Act for Fiscal Year 1989".

SEC. 102. AUTHORIZATIONS FOR PROGRAM ACTIVITIES.

(a) AUTHORIZATIONS. —There are authorized to be appropriated to the Secretary of Commerce (hereafter in this Act referred to as the "Secretary"), for fiscal year 1989, to carry out activities performed by the National Institute of Standards and Technology, the sums set forth in the following line items:

(1) Measurement Research and Standards, $43,220,000.

(2) Materials Science and Engineering, $24,054,000.

(3) Engineering Measurements and Standards, $49,098,000.

(4) Computer Science and Technology, $11,000,000.

(5) Research Support Activities, $20,867,000.

(6) Cold Neutron Source Facility, $6,500,000 (for a total authorization of $19,500,000).

(7) Technology Services, $3,300,000.

(b) LIMITATIONS. —Notwithstanding any other provision of this or any other Act—

(1) of the total of the amounts authorized under subsection (a), $2,000,000 is authorized only for steel technology;

(2) of the total amount authorized under paragraph (3) of subsection (a)—

(A) $4,000,000 is authorized only for the Center for Building Technology, and

(B) $6,000,000 is authorized only for the Center for Fire Research, and the two Centers shall not be merged;

(3) of the total amount authorized under paragraph (5) of subsection (a), $7,500,000 is authorized only for the technical competence fund; and

(4) of the amount authorized under paragraph (7) of subsection (a)—

(A) $3,000,000 is authorized only for the support of Regional Centers for the Transfer of Manufacturing Technology, and Assistance to State Technology Programs;

(B) $300,000 is authorized only for the evaluation of nonenergy-related inventions and related technology extension activities; and

(C) funds authorized under subparagraph (A) shall be used only to award, amend, or renew research cooperative agreements entered into pursuant to the competitive process established by the National Bureau of Standards for this program (53 Fed. Reg. 27060; July 18, 1988).

(c) TRANSFERS. —

(1) Funds may be transferred among the line items listed in subsection (a), so long as the net funds transferred to or from any line item do not exceed 10 percent of the amount authorized for that line item in such subsection and the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives are notified in advance of any such transfer.

(2) In addition, the Secretary may propose transfers to or from any line item exceeding 10 percent of the amount authorized for the line item in subsection (a); but such proposed transfer may not be made—

(A) unless a full and complete explanation of any such proposed transfer and the reason therefore are transmitted in writing to the Speaker of the House of Representatives, the President of the Senate, and the appropriate authorizing committees of the House of Representatives and the Senate, and

(B) 30 calendar days have passed following the transmission of such written explanation.

(d) PUBLICATION IN FEDERAL REGISTER. —The requirement of section 25(c)(2) of the Act of March 3, 1901, shall be considered to have been met by the publication made by the National Bureau of Standards on July 18, 1988 (53 Fed. Reg. 27060).

SEC. 103. UNDER SECRETARY FOR TECHNOLOGY.

In addition to any sums otherwise authorized by this title, there are authorized to be appropriated to the Secretary for fiscal year 1989—

(1) $1,000,000 for the activities of the Office of the Under Secretary of Commerce for Technology, as established in section 201(a); and

(2) $2,000,000 for the activities of the Office of Technology Policy, as established in such section.

SEC. 104. JAPANESE TECHNICAL LITERATURE.

In addition to any sums otherwise authorized by this title, there is authorized to be appropriated to the Secretary for fiscal year 1989 the sum of $1,000,000 to carry out the purposes of the Japanese Technical Literature Act of 1986 (Public Law 99-382; 100 Stat. 811).

SEC. 105. SALARY ADJUSTMENTS.

In addition to any sums otherwise authorized by this title, there are authorized to be appropriated to the Secretary for fiscal year 1989 such additional sums as may be necessary to make any adjustments in salary, pay, retirement, and other employee benefits which may be provided for by law.

SEC. 106. AVAILABILITY OF APPROPRIATIONS.

Appropriations made under the authority provided in this title shall remain available for obligation, for expenditure, or for obligation and expenditure for periods specified in the Acts making such appropriations.

SEC. 107. RESEARCH INFORMATION CENTER.

The Research Information Center of the National Bureau of Standards shall be maintained as a governmental activity under the National Institute of Standards and Technology.

SEC. 108. EVALUATED ENGINEERING DATA STUDY.

Within 6 months after the date of the enactment of this Act, the Director of the National Institute of Standards and Technology shall conduct a study of needs within the private and public sectors for evaluated engineering data, and shall submit a report to the Congress making recommendations concerning the appropriate roles of the National Institute of Standards and Technology, other government agencies, professional societies, and trade associations in the collection, evaluation, and dissemination of such data. Such recommendations shall, among other things, address plans for the dissemination of the results of the study through data bases, and plans for incorporating high quality results from other countries.

SEC. 109. TECHNOLOGY SERVICES.

In addition to such other technology services and technology extension activities which may be mandated or authorized by law, and in order to help improve the use of technology by small and medium-sized industrial firms within the United States, the Director of the National Institute of Standards and Technology, as appropriate, shall—

(1) work directly with States, local governments, and other appropriate organizations to provide for extended distribution of Standard Reference Materials, Standard Reference Data, calibrations, and related technical services and to help transfer other expertise and technology to the States and to small businesses and other businesses within the States;

(2) evaluate those inventions from small businesses or individuals which have a significant potential for improving competitiveness;

(3) provide support for workshops on technical and entrepreneurial topics and share information developed through the Malcolm Baldrige Quality Award Program; and

(4) work with other Federal agencies to provide technical and related assistance to the States and businesses within the States.

SEC. 110. TECHNOLOGY TRANSFER.

Within 6 months after the date of the enactment of this Act, the Director of the National Institute of Standards and Technology shall report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives on domestic technology transfer accomplishments, trends, and plans since 1986 at the National Bureau of Standards and the National Institute of Standards and Technology. Such report shall describe with examples the types of technology transfer undertaken by the National Bureau of Standards or the National Institute of Standards and Technology, the amount of funds devoted to these efforts, and patent and licensing activities related to the National Bureau of Standards and the National Institute of Standards and Technology research results. The report shall describe the division of technology transfer activities between the Gaithersburg, Maryland, and Boulder, Colorado, sites of the National Institute of Standards and Technology. The merits of establishing a technology transfer office in Boulder or of giving the Boulder laboratories increased technology transfer responsibilities shall also be considered.

SEC. 111.

ANNUAL BUDGET SUBMISSION.

The National Institute of Standards and Technology shall annually submit to the Congress, at the time of the release of the President's budget, a three year budget estimate for the Institute, including funding estimates for each major account and new initiative.

SEC. 112.

INTERNATIONAL STANDARDS.

(a) PROGRAM. —The Secretary, acting through the Director of the National Institute of Standards and Technology and other appropriate officials, shall seek funding for and establish, within 6 months after the date of the enactment of this Act, a program to assist other countries in the development of their domestic standards which are compatible with standards in general use in the United States. After the program is established, it shall be funded through voluntary contributions from the private sector to fully reimburse the United States for expenses incurred during fiscal years 1989 and 1990. The program shall begin on a pilot basis focusing on one or two countries or groups of countries which are major United States trading partners and have expressed interest in such program. The Secretary shall ensure that contributions which are earmarked by country are spent to assist the development of standards by that country or group of countries.

(b) LONG-TERM PLAN. —No later than June 30, 1989, the Secretary shall submit to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate a long-term plan for assistance under this section for each nation or group of nations which annually has imports of at least $1,000,000,000 from the United States (or has the potential for being a major importer from the United States) and which desires such assistance. The plan shall include a description of the resources needed to provide such assistance, the appropriate and likely sources of such funds, and the appropriate relationship between the program established under this section and private sector standards organizations. Special consideration is to be given to the feasibility of establishing a data base and other methods for making standards information developed in cooperation with one country available to other countries.

TITLE II—TECHNOLOGY ADMINISTRATION IN THE DEPARTMENT OF COMMERCE

SUBTITLE A—TECHNOLOGY ADMINISTRATION

SEC. 201. TECHNOLOGY ADMINISTRATION.

(a) ESTABLISHMENT. —Section 5(a) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3704(a)) is amended to read as follows:

(a) ESTABLISHMENT. —There is established in the Department of Commerce a Technology Administration, which shall operate in accordance with the provisions, findings, and purposes of this Act. The Technology Administration shall include—

"(1) the National Institute of Standards and Technology;

"(2) the National Technical Information Service; and

"(3) a policy analysis office, which shall be known as the Office of Technology Policy."

(b) UNDER SECRETARY AND ASSISTANT SECRETARY. —Section 5(b) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3704(b)) is amended to read as follows:

(b) UNDER SECRETARY AND ASSISTANT SECRETARY. —The President shall appoint, by and with the advice and consent of the Senate, to the extent provided for in appropriations Acts—

"(1) an Under Secretary of Commerce for Technology, who shall be compensated at the rate provided for level III of the Executive Schedule in section 5314 of title 5, United States Code; and

"(2) an Assistant Secretary of Commerce for Technology Policy, who shall serve as policy analyst for the Under Secretary."

(c) DUTIES. —Section 5(c) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3704(c)) is amended—

(1) by redesignating paragraphs (1) through (10) as paragraphs (5) through (14), respectively;

(2) by striking "Assistant Secretary, on a continuing basis, shall—" and inserting in lieu thereof "Under Secretary, as appropriate, shall—

"(1) manage the Technology Administration and supervise its agencies, programs, and activities;

"(2) conduct technology policy analyses to improve United States industrial productivity, technology, and innovation, and cooperate with United States industry in the improvement of its productivity, technology, and ability to compete successfully in world markets;

"(3) carry out any functions formerly assigned to the Office of Productivity, Technology, and Innovation

"(4) assist in the implementation of the Metric Conversion Act of 1975;" and

(3) in paragraph (10), as redesignated by paragraph (1) of this subsection, by striking "Assistant Secretary" and inserting in lieu thereof "Under Secretary".

(d) CONFORMING AMENDMENTS. —

(1) Section 4 of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3703) is amended—

(A) in paragraph (1), by striking "Productivity, Technology, and Innovation" and inserting in lieu thereof "Technology Policy"; and

(B) by amending paragraph (3) to read as follows:

"(3) 'Under Secretary' means the Under Secretary of Commerce for Technology appointed under section 5(b)(1).".

(2) Section 5(d)(1) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3704(d)(1)) is amended by striking "shall establish and, through the National Technical Information Service and" and inserting in lieu thereof "and the Under Secretary shall establish, and through the National Technical Information Service and with the cooperation of".

(3) Section 11(g)(1) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3710(g)(1)) is amended by inserting "through the Under Secretary, and" after "Secretary,"

(4) Section 5314 of title 5, United States Code, is amended by adding at the end the following item: "Under Secretary of Commerce for Technology."

(e) TRANSITION. —The individual serving as the Assistant Secretary of Commerce for Productivity, Technology, and Innovation immediately before the date of enactment of this Act shall serve as Acting Assistant Secretary of Commerce for Technology Policy until the Assistant Secretary takes office.

SUBTITLE B—NATIONAL TECHNICAL INFORMATION SERVICE

SEC. 211.

SHORT TITLE.

This subtitle may be cited as the "National Technical Information Act of 1988".

SEC. 212.

NATIONAL TECHNICAL INFORMATION SERVICE.

(a) POWERS. —(1) The Secretary of Commerce, acting through the Director of the National Technical Information Service (hereafter in this subtitle referred to as the "Director") is authorized to do the following:

(A) Enter into such contracts, cooperative agreements, joint ventures, and other transactions, in accordance with all relevant provisions of Federal law applicable to such contracts and agreements, and under reasonable terms and conditions, as may be necessary in the conduct of the business of the National Technical Information Service (hereafter in this subtitle referred to as the "Service").

(B) In addition to the authority regarding fees contained in section 2 of the Act entitled "An Act to provide for the dissemination of technological, scientific, and engineering information to American business and industry, and for other purposes" enacted September 9, 1950 (15 U.S.C. 1152), retain and, subject to appropriations Acts, utilize its net revenues to the extent necessary to implement the plan submitted under subsection (f)(3)(D).

(C) Enter into contracts for the performance of part or all of the functions performed by the Promotion Division of the Service prior to the date of the enactment of this Act. The details of any such contract, and a statement of its effect on the operations and personnel of the Service, shall be provided to the appropriate committees of the Congress 30 days in advance of the execution of such contract.

(D) Employ such personnel as may be necessary to conduct the business of the Service. An increase or decrease in the personnel of the Service shall not affect or be affected by any ceilings on the number or grade of personnel.

(2) The functions and activities of the Service specified in subsection (e) (1) through (6) are permanent Federal functions to be carried out by the Secretary through the Service and its employees, and shall not be transferred from the Service, by contract or otherwise, to the private sector on a permanent or temporary basis without express approval of the Congress. Functions or activities—

(A) for the procurement of supplies, materials, and equipment by the Service;

(B) referred to in paragraph (1)(C); or

(C) to be performed through joint ventures or cooperative agreements which do not result in a reduction in the Federal workforce of the affected programs of the service, shall not be considered functions or activities for purposes of this paragraph.

(3) For the purposes of this subsection, the term "net revenues" means the excess of revenues and receipts from any source, other than royalties and other income described in section 13(a)(4) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3710c(a)(4)), over operating expenses.

(4) Section 11(h) of the Stevenson-Wydler Technology Innovation Act of 1980 is repealed.

(b) DIRECTOR OF THE SERVICE. —The management of the Service shall be vested in a Director who shall report to the Under Secretary of Commerce for Technology and the Secretary of Commerce.

(c) ADVISORY BOARD. —(1) There is established the Advisory Board of the National Technical Information Service, which shall be composed of a chairman and four other members appointed by the Secretary.

(2) In appointing members of the Advisory Board the Secretary shall solicit recommendations from the major users and beneficiaries of the Service's activities and shall select individuals experienced in providing or utilizing technical information.

(3) The Advisory Board shall review the general policies and operations of the Service, including policies in connection with fees and charges for its services, and shall advise the Secretary and the Director with respect thereto.

(4) The Advisory Board shall meet at the call of the Secretary, but not less often than once each six months.

(d) AUDITS. —The Secretary of Commerce shall provide for annual independent audits of the Service's financial statements beginning with fiscal year 1988, to be conducted in accordance with generally accepted accounting principles.

(e) FUNCTIONS. —The Secretary of Commerce, acting through the Service, shall—

(1) establish and maintain a permanent repository of nonclassified scientific, technical, and engineering information;

(2) cooperate and coordinate its operations with other Government scientific, technical, and engineering information programs;

(3) make selected bibliographic information products available in a timely manner to depository libraries as part of the Depository Library Program of the Government Printing Office;

(4) in conjunction with the private sector as appropriate, collect, translate into English, and disseminate unclassified foreign scientific, technical, and engineering information;

(5) implement new methods or media for the dissemination of scientific, technical, and engineering information; and

(6) carry out the functions and activities of the Secretary under the Act entitled "An Act to provide for the dissemination of technological, scientific, and engineering information to American business and industry, and for other purposes" enacted September 9, 1950, and the functions and activities of the Secretary performed through the National Technical Information Service as of the date of enactment of this Act under the Stevenson-Wydler Technology Innovation Act of 1980.

(f) NOTIFICATION OF CONGRESS. —

(1) The Secretary of Commerce and the Director shall keep the appropriate committees of Congress fully and currently informed about all activities related to the carrying out of the functions of the Service, including changes in fee policies.

(2) Within 90 days after the date of the enactment of this Act, the Secretary of Commerce shall submit to the Congress a report on the current fee structure of the Service, including an explanation of the basis for the fees, taking into consideration all applicable costs, and the adequacy of the fees, along with reasons for the declining sales at the Service of scientific, technical, and engineering publications. Such report shall explain any actions planned or taken to increase such sales at reasonable fees.

(3) The Secretary shall submit an annual report to the Congress which shall—

(A) summarize the operations of the Service during the preceding year, including financial details and staff levels broken down by major activities;

(B) detail the operating plan of the Service, including specific expense and staff needs, for the upcoming year;

(C) set forth details of modernization progress made in the preceding year;

(D) describe the long-term modernization plans of the Service; and

(E) include the results of the most recent annual audit carried out under subsection (d).

(4) The Secretary shall also give the Congress detailed advance notice of not less than 30 calendar days of—

(A) any proposed reduction-in-force;

(B) any joint venture or cooperative agreement which involves a financial incentive to the joint venturer or contractor; and

(C) any change in the operating plan submitted under paragraph (3)(B) which would result in a variation from such plan with respect to expense levels of more than 10 percent.

TITLE III—MISCELLANEOUS AMENDMENTS TO STEVENSON-WYDLER TECHNOLOGY INNOVATION ACT OF 1980

SEC. 301. COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENTS.

Section 12 of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3710a) is amended—

(1) in subsection (a)(2), by striking "at the laboratory and other inventions" and inserting in lieu thereof "or other intellectual property developed at the laboratory and other inventions or other intellectual property"; and

(2) in subsection (b)—

(A) by striking "and" at the end of paragraphs (2) and (3);

(B) by redesignating paragraph (4) as paragraph (5); and

(C) by inserting after paragraph (3) the following new paragraph:

"(4) determine rights in other intellectual property developed under an agreement entered into under subsection (a)(1); and".

SEC. 302. REWARDS.

Section 13(1) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3710b(1)) is amended by inserting "computer software", after "inventions, innovations,"

SEC. 303. DISTRIBUTION OF ROYALTIES.

(a) Section 14(a)(1)(A) of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3710c(a)(1)(A)) is amended—

(1) in clause (i), by striking "was an employee of the agency at the time the invention was made" and inserting in lieu thereof "has assigned his or her rights in the invention to the United States"; and

(2) in clause (ii), by striking "who were employed by the agency at the time the invention was made and whose names appear on licensed inventions" and inserting in lieu thereof "under clause (i)".

(b) This section shall be effective as of October 20, 1986.

TITLE IV—DRUG-FREE WORKPLACE

SEC. 401. DRUG-FREE WORKPLACE.

(a) No department, agency, or instrumentality of the United States receiving funds authorized to be appropriated under this Act for fiscal year 1989 or under any other Act authorizing appropriations for fiscal year 1989 for the National Institute of Standards and Technology (hereafter in this section referred to as the "Institute"), shall obligate or expend any such funds, unless the Institute has in place, and will continue to administer in good faith, a written policy designed to ensure that all of its workplaces are free from the illegal use, possession, or distribution of controlled substances (as defined in the Controlled Substances Act) by the officers and employees of the Institute.

(b) No funds so authorized to be appropriated to the Institute for fiscal year 1989 shall be available for payment in connection with any grant, contract, or other agreement, unless the recipient of such grant, contractor, or party to such agreement, as the case may be, has in place and will continue to administer in good faith a written policy, adopted by such recipient, contractor, or party's board of directors or other governing authority, satisfactory to the Director of the Institute, designed to ensure that all of the workplaces of such recipient, Contractor, or party are free from the illegal use, possession, or distribution of controlled substances (as defined in the Controlled Substances Act) by the officers and employees of such recipient, contractor, or party.

* * * * *

November 17, 1988, 102 Stat. 4073 (Public Law 100-680—100th Congress, 2d session) Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988.

Public Law 100-680

AN ACT

To promote energy conservation and technology competitiveness in the American steel and aluminum industries.

SEC. 7. (102 Stat. 4076) The National Institute of Standards and Technology, through its Institute for Materials Science and Engineering and, as appropriate, in coordination with the Department of Energy and other Federal agencies, shall conduct an expanded program of steel and aluminum research to provide necessary instrumentation and measurement research and development in support of activities conducted under this Act.

* * * * *

November 19, 1988, 102 Stat. 4613 (Public Law 100-697—100th Congress, 2d session) National Superconductivity and Competitiveness Act of 1988.

Public Law 100-697

AN ACT

To establish a national Federal program effort in close collaboration with the private sector to develop as rapidly as possible the applications of superconductivity to enhance the Nation's economic competitiveness and strategic well-being, and for other purposes.

SEC. 5. (102 Stat. 4615) In pursuance of the goals of this Act, the National Institute of Standards and Technology shall promote fundamental research and materials standards to accelerate the use and application of the new superconducting materials, and shall utilize the Superconductivity Center Focusing on Electronic Applications at the National Institute of Standards and Technology in Boulder, Colorado.

* * * * *

November 21, 1989, 103 Stat. 988 (Public Law 101-162—101th Congress, 1st session) Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations act, 1990 Appropriations Act, 1990.

Public Law 101-162

AN ACT

Making appropriations for the Departments of Commerce, Justice, and State, the Judiciary, and related agencies for the fiscal year ending September 30, 1990, and for other purposes.

(103 Stat. 993) National Institute of Standards and Technology. Scientific and Technical Research and Services. For necessary expenses of the core programs of the National Institute of Standards and Technology, $144,809,000, to remain available until expended, of which not to exceed $3,430,000 may be transferred to the "Working Capital Fund"; and of which not to exceed $1,300,000 shall be available for construction of research facilities; and in addition for grants for regional centers for the transfer of manufacturing technology as authorized by section 5121 of the Omnibus Trade and Competitiveness Act of 1988, $7,500,000, to remain available until expended; and in addition for expenses of the Advanced Technology Program as authorized by section 5131 of the Omnibus Trade and Competitiveness Act of 1988, $10,000,000, to remain available until expended; and in addition for technology transfer extension services pursuant to section 5121 of the Omnibus Trade and Competitiveness Act of 1988, $1,300,000, to remain available until expended.

* * * * *

December 11, 1989, 103 Stat. 1859 (Public Law 101-218—101th Congress, 1st session) Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989.

Public Law 101-218

AN ACT

To provide Federal assistance and leadership to a program of research, development, and demonstration of renewable energy and energy efficiency technologies, and for other purposes.

Sec. 6. (3) (103 Stat. 1863) Advisory Committee. The Secretary shall establish an Advisory Committee on Renewable Energy and Energy Efficiency Joint Ventures.... to advise the Secretary on the development of the solicitation and evaluation criteria for joint ventures....The Secretary shall appoint members to the Advisory committee, including at least one member representing-....the National Institute of Standards and Technology....

* * * * *

August 10, 1990, 104 Stat. 405 (Public Law 101-352—101th Congress, 2d session) Fire Safe Cigarette Act of 1990.

Public Law 101-352

AN ACT

To direct the completion of the research recommended by the Technical Study Group on Cigarette and Little Cigar Fire Safety and to provide for an assessment of the practicality of a cigarette fire safety performance standard.

SEC. 2 (a) (104 Stat. 405) Center for Fire Research.—

At the request of the Consumer Product Safety Commission, the National Institute for Standards and Technology's Center for Fire Research shall—

(1) develop a standard test method to determine cigarette ignition propensity,

(2) compile performance data for cigarettes using the standard test method developed under paragraph (1), and

(3) conduct laboratory studies on and computer modeling of ignition physics to develop valid, user-friendly predictive capability.

SEC. 3. (a) (104 Stat. 406) Establishment.—

There is established the Technical Advisory Group to advise and work with the Consumer Product Safety Commission and National Institute for Standards and Technology's Center for Fire Research on the implementation of this Act.

SEC. 5. (a) (104 Stat. 406) In General.—

Any information provided to the National Institute for Standards and Technology's Center for Fire Research...is designated as trade secret or confidential information...

* * * * *

August 18, 1990, 104 Stat. 484 (Public Law 101-380—101th Congress, 2d session) Oil Pollution Act of 1990.

Public Law 101-380

AN ACT

To establish limitations on liability for damages resulting from oil pollution, to establish a fund for the payment of compensation for such damages, and for other purposes.

Title VII-Oil Pollution Research and Development Program.

SEC. 7001.

(a) (104 Stat. 559) Interagency Coordinating Committee on Oil Pollution Research.

(3) Membership.-The Interagency Committee shall include representatives from the Department of Commerce (including the National Oceanic and Atmospheric Administration and the National Institute of Standards and Technology)...

(b) Oil Pollution Research and Technology Plan.—

(2) ... The National Institute of Standards and Technology shall provide the Interagency Committee with advice and guidance on issues relating to quality assurance and standards measurements relating to its activities under this section.

* * * * *

November 5, 1990, 104 Stat. 1388 (Public Law 101-508—101th Congress, 2d session) Omnibus Budget Reconciliation Act of 1990.

Public Law 101-508

AN ACT

To provide for reconciliation pursuant to section 4 of the concurrent resolution on the budget for fiscal year 1991.

SEC. 10205. (104 Stat. 1388-394) National Institute of Standards and Technology Cost Recovery Study.

(a) The Secretary of Commerce shall undertake a study of current practices at, and any suggested improvements consistent with the mission of, the National Institute of Standards and Technology for recovering the costs of services and materials provided to private and nonprofit organizations, including services provided on a proprietary basis to users of Institute facilities.

* * * * *

November 5, 1990, 104 Stat. 2101 (Public Law 101-515—101th Congress, 2d session) Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations Act, 1991.

Public Law 101-515

AN ACT

Making appropriations for the Departments of Commerce, Justice, and State, the Judiciary, and related agencies for the fiscal year ending September 30, 1991, and for other purposes.

(104 Stat. 2106-7) National Institute of Standards and Technology. Scientific and Technical Research and Services. For necessary expenses of the National Institute of Standards and Technology, $166,228,000, to remain available until expended, of which not to exceed $9,772,000 may be transferred to the "Working Capital Fund"; and of which not to exceed $10,095,000 shall be available for construction of research facilities. Industrial Technology Services. For necessary expenses of the Regional Centers for the transfer of Manufacturing Technology, and the Advanced Technology and State Extension Services programs of the National Institute of Standards and Technology, $49,100,000, to remain available until expended. Sec. 105. (a) (104 Stat. 2108) Funds appropriated by this Act to the National Institute of Standards and Technology of the Department of Commerce for the Advanced Technology Program shall be available for award to companies or to joint ventures under the terms and conditions set forth in subsection (b) of this section, in addition to any terms and conditions established by rules issued by the Secretary of Commerce.

* * * * *

November 15, 1990, 104 Stat. 2399 (Public Law 101-549—101st, Congress, 2d session) Clean Air Act, Amendments.

Public Law 101-549

AN ACT

To amend the Clean Air Act to provide for attainment and maintenance of health protective national ambient air quality standards, and for other purposes.

SEC. 901. (b) (104 Stat. 2701-2702) Title IX-Clean Air Research.

"(A) The creation of an Interagency Task Force to coordinate such program. The Task Force shall include representatives of the ..., the National Institute of Standards and Technology, ...

* * * * *

November 15, 1990, 104 Stat. 2814 (Public Law 101-574—101th Congress, 2d session) Small Business Administration Reauthorization and Amendments Act of 1990.

Public Law 101-574

AN ACT

To amend the Small Business Act and the Small Business Investment Act of 1958, and for other purposes.

SEC. 232. (104 Stat. 2824) Pilot Technology Access Program.

(a) Establishment.-The Small Business Administration, in consultation with the National Institute of Standards and Technology and the National Technical Information Service, shall establish a Pilot Technology Access Program (hereafter in this section referred to as the "Program"), for making grants under this section to a maximum of 5 States.

* * * * *

November 16, 1990, 104 Stat. 2943 (Public Law 101-592—101th Congress, 2d session) Fastener Quality Act.

Public Law 101-592

AN ACT

To require that certain fasteners sold in commerce conform to the specifications to which they are represented to be manufactured, to provide for accreditation of laboratories engaged in fastener testing, to require inspection, testing, and certification, in accordance with standardized methods, of fasteners used in critical applications to increase fastener quality and reduce the danger of fastener failure, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

[*1] SECTION 1.

SHORT TITLE.

This Act may be cited as the "Fastener Quality Act".

[*3] SEC. 3. DEFINITIONS.

As used in this Act, the term—

(4) "Director" means the Director of the National Institute of Standards and Technology;

(8) "Institute" means the National Institute of Standard and Technology;

(13) "Secretary" means the Secretary of Commerce;

SEC. 6. LABORATORY ACCREDITATION.

(a) ESTABLISHMENT OF ACCREDITATION PROGRAM. —(1) Within 180 days after the date of enactment of this Act, the Secretary, acting through the Director, shall issue regulations which shall include—

(A) procedures and conditions, including sampling procedures referred to in section 5, for the accreditation by the Institute of laboratories engaged in the inspection and testing of fasteners under section 5;

(B) procedures and conditions (which shall be consistent with the procedures and conditions established under subparagraph (A)), using to the extent practicable the requirements of national or international consensus documents intended to govern the operation of accreditation bodies, under which private entities may apply for approval by the Secretary to engage directly in the accreditation of laboratories in accordance with the requirements of this Act; and

(C) conditions (which shall be consistent with the procedures and conditions established under subparagraph (A)), under which the accreditation of foreign laboratories by their governments or organizations recognized by the Director shall be deemed to satisfy the laboratory accreditation requirements of this section.

(2) Upon establishing a laboratory accreditation program under paragraph (1), the Secretary shall publish a notice in the Federal Register stating that the Secretary is prepared to accept applications for accreditation of such laboratories.

(3) No accreditation provided under the terms of this subsection shall be effective for a period of greater than 3 years.

(b) LABORATORY ACCREDITATION PROCEDURES. —Existing Institute accreditation procedures stated in part 7 of title 15, Code of Federal Regulations, as in effect on the date of enactment of this Act, supplemented as the Secretary considers necessary, shall be used to accredit laboratories under the accreditation program established under subsection (a).

(c) ENSURING COMPLIANCE. —(1) The Secretary shall ensure that—

(A) private entities accrediting laboratories under procedures and conditions established under subsection (a)(1)(B) comply with such procedures and conditions, and

(B) laboratories accredited by such private entities, or by foreign governments pursuant to subsection (a)(1)(C), comply with the requirements for such accreditation.

(2) The Secretary may require any such private entity or laboratory to provide all records and materials that may be necessary to allow the Secretary to carry out this subsection.

(d) OPERATION OF LABORATORY ACCREDITATION PROGRAM. —

(1) The Director may hire such contractors as are necessary to carry out the accreditation program established under subsection (a).

(2) Costs to the Institute and to the Secretary for the establishment and operation of the accreditation program under this section shall be fully reimbursable to the Institute or to the Secretary, as appropriate, through fees or other charges for accreditation services under such program.

(e) RECOMMENDATIONS TO CONSENSUS STANDARDS ORGANIZATIONS. —The Director shall periodically transmit to appropriate consensus standards organizations any information or recommendations that may be useful in the establishment or application by such organizations of standards and specifications for fasteners.

* * * * *

November 16, 1990, 104 Stat. 3231 (Public Law 101-614—101th Congress, 2d session) National Earthquake Hazards Reduction Program Reauthorization Act.

Public Law 101-614

AN ACT

To authorize appropriations for the Earthquake Hazards Reduction Act of 1977, and for other purposes.

SEC. 4. (1) (104 Stat. 3232) Definitions. ... "(7) The term 'Program agencies' means the Federal Emergency Management Agency, the United States Geological Survey, the National Science Foundation, and the National Institute of Standards and Technology."

SEC. 5. (b)(2)(A) (104 Stat. 3233) "(iii) prepare and disseminate widely, with the assistance of the National Institute of Standards and Technology, other Federal agencies, and private sector groups, information on building codes and practices for structures and lifelines;

SEC. 5. (b)(5) (104 Stat. 3236) National Institute of Standards and Technology.-The National Institute of Standards and Technology shall be responsible for carrying out research and development to improve building codes and standards and practices for structures and lifelines. In carrying out this paragraph, the Director of the National Institute of Standards and Technology shall—

(A) work closely with national standards and model building code organizations, in conjunction with the Agency, to promote the implementation of research results;

(B) promote better building practices among architects and engineers; and

(C) work closely with national standards organizations to develop seismic safety standards and practices for new and existing lifelines.

SEC. 8. (a)(1) (104 Stat. 3237-8) Adoption of Standards.

The President shall adopt, not later than December 1, 1994, standards for assessing and enhancing the seismic safety of existing buildings constructed for or leased by the Federal Government which were designed and constructed without adequate seismic design and construction standards. Such standards shall be developed by the Interagency Committee on Seismic Safety in Construction, whose chairman is the Director of the National Institute of Standards and Technology or his designee, and which shall work in consultation with appropriate private sector organizations. ...

(b) Lifelines.-The Director of the Agency, in consultation with the Director of the National Institute of Standards and Technology, shall submit to the Congress, not later that June 30, 1992, a plan, including precise timetables and budget estimates, for developing and adopting, in consultation with appropriate private sector organizations, design and construction standards for lifelines. The plan shall include recommendations of ways Federal regulatory authority could be used to expedite the implementation of such standards."

SEC. 11. (104 Stat. 3239) Post-Earthquake Investigations Program. ... The Director of the Survey is authorized to utilize earthquake expertise from the Agency, the National Science Foundation, the National Institute of Standards and Technology, other Federal agencies, and private contractors, on a reimbursable basis, in the conduct of such earthquake investigations. At a minimum, investigations under this section shall include—

(1) analysis by the National Science Foundation and the United States Geological Survey of the causes of the earthquake and the nature of the resulting ground motion;

(2) analysis by the National Science Foundation and the National Institute of Standards and Technology of the behavior of structures and lifelines, both those that were damaged and those that were undamaged; and ...

SEC. 14. (b) (104 Stat. 3242) Study on Improving Earthquake Mitigation.— ... The Director of the Federal Emergency Management Agency shall appoint, in consultation with the United States Geological Survey, the National Institute of Standards and Technology, and the National Science Foundation, a panel of experts in relevant fields and activities to undertake such study ...

* * * * *

December 9, 1991, 105 Stat. 1594 (Public Law 102-194—102nd Congress, 1st session) High-Performance Computing Act of 1991.

Public Law 102-194

AN ACT

To provide for a coordinated Federal program to ensure continued United States leadership in high-performance computing.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

[*1] SECTION 1.

SHORT TITLE.

This Act may be cited as the "High-Performance Computing Act of 1991".

TITLE II—AGENCY ACTIVITIES

[*204] SEC. 204.

DEPARTMENT OF COMMERCE ACTIVITIES.

(a) General Responsibilities. As part of the Program described in title I—

(1) the National Institute of Standards and Technology shall—

(A) conduct basic and applied measurement research needed to support various high-performance computing systems and networks;

(B) develop and propose standards and guidelines, and develop measurement techniques and test methods, for the interoperability of high-performance computing systems in networks and for common user interfaces to systems; and

(C) be responsible for developing benchmark tests and standards for high-performance computing systems and software; and

(2) the National Oceanic and Atmospheric Administration shall conduct basic and applied research in weather prediction and ocean sciences, particularly in development of new forecast models, in computational fluid dynamics, and in the incorporation of evolving computer architectures and networks into the systems that carry out agency missions.

(b) High-Performance Computing and Network Security. Pursuant to the Computer Security Act of 1987 (Public Law 100-235; 101 Stat. 1724), the National Institute of Standards and Technology shall be responsible for developing and proposing standards and guidelines needed to assure the cost-effective security and privacy of sensitive information in Federal computer systems.

(c) Study of Impact of Federal Procurement Regulations.

(1) The Secretary of Commerce shall conduct a study to—

(A) evaluate the impact of Federal procurement regulations that require that contractors providing software to the Federal Government share the rights to proprietary software development tools that the contractors use to develop the software; and

(B) determine whether such regulations discourage development of improved software development tools and techniques.

(2) The Secretary of Commerce shall, within one year after the date of enactment of this Act, report to the Congress regarding the results of the study conducted under paragraph (1).

(d) Authorization of Appropriations. From sums otherwise authorized to be appropriated, there are authorized to be appropriated—

(1) to the National Institute of Standards and Technology for the purposes of the Program $3,000,000 for fiscal year 1992; $4,000,000 for fiscal year 1993; $5,000,000 for fiscal year 1994; $6,000,000 for fiscal year 1995; and $7,000,000 for fiscal year 1996; and

(2) to the National Oceanic and Atmospheric Administration for the purposes of the Program $2,500,000 for fiscal year 1992; $3,000,000 for fiscal year 1993; $3,500,000 for fiscal year 1994; $4,000,000 for fiscal year 1995; and $4,500,000 for fiscal year 1996. year 1994; $6,500,000 for fiscal year 1995; and $7,000,000 for fiscal year 1996. on $1,500,000 for fiscal year 1992; $1,700,000 for fiscal year 1993; $1,900,000 for fiscal year 1994; $2,100,000 for fiscal year 1995; and $2,300,000 for fiscal year 1996.

SEC. 208 FOSTERING UNITED STATES COMPETITIVENESS IN HIGH-PERFORMANCE COMPUTING AND RELATED ACTIVITIES.

(c) Review of Supercomputer Agreement.—

(1) Report. The Under Secretary for Technology Administration of the Department of Commerce (in this subsection referred to as the "Under Secretary") shall conduct a comprehensive study of the revised "Procedures to Introduce Supercomputers" and the accompanying exchange of letters between the United States and Japan dated June 15, 1990 (commonly referred to as the "Supercomputer Agreement") to determine whether the goals and objectives of such Agreement have been met and to analyze the effects of such Agreement on United States and Japanese supercomputer manufacturers. Within 180 days after the date of enactment of this Act, the Under Secretary shall submit a report to Congress containing the results of such study.

(2) Consultation. In conducting the comprehensive study under this subsection, the Under Secretary shall consult with appropriate Federal agencies and departments and with United States manufacturers of supercomputers and other appropriate private sector entities.

* * * * *

February 14, 1992, 106 Stat. 7 (Public Law 102-245—-102nd Congress, 2nd session) American Technology Preeminence Act of 1991.

Public Law 102-245

AN ACT

To authorize appropriations for the National Institute of Standards and Technology and the Technology Administration of the Department of Commerce, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "American Technology Preeminence Act of 1991".

TITLE I—DEPARTMENT OF COMMERCE RESEARCH AND TECHNOLOGY

SEC. 101.

SHORT TITLE.

This title may be cited as the "Technology Administration Authorization Act of 1991".

SEC. 102.

STATEMENT OF POLICY.

Congress finds that in order to help United States industries to speed the development of new products and processes so as to maintain the economic competitiveness of the Nation, it is necessary to strengthen the programs and activities of the Department of Commerce's Technology Administration and National Institute of Standards and Technology.

SEC. 104. NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY.

(a) Fiscal Year 1992.

(1) There are authorized to be appropriated to the Secretary, to carry out the intramural scientific and technical research and services activities of the Institute, $210,000,000 for fiscal year 1992, which shall be available for the following line items:

(A) Electronics and Electrical Measurements, $33,700,000.
(B) Manufacturing Engineering, $13,500,000.
(C) Chemical Science and Technology, $22,000,000.
(D) Physics, $27,000,000.
(E) Materials Science and Engineering, $30,000,000.
(F) Building and Fire Research, $12,300,000.
(G) Computer Systems, $16,000,000.
(H) Applied Mathematics and Scientific Computing, $6,500,000.
(I) Technology Assistance, $11,000,000.
(J) Research Support Activities, $38,000,000.

(2) (A) Of the total of the amounts authorized under paragraph (1), $2,000,000 are authorized only for steel technology.

(B) Of the amount authorized under paragraph (1)(I)—

(i) $500,000 are authorized only for the evaluation of nonenergy-related inventions and related technology extension activities;

(ii) $250,000 are authorized only for Institute participation in the pilot program established under subsection (e); and

(iii) $2,700,000 are authorized only for the Institute's management of the extramural funding programs authorized under section 105.

(C) Of the total amount authorized under paragraph (1)(J), $7,565,000 are authorized only for the technical competence fund.

(b) Fiscal Year 1993. (1) There are authorized to be appropriated to the Secretary, to carry out the intramural scientific and technical research and services activities of the Institute, $221,200,000 for fiscal year 1993, which shall be available for the following line items:
(A) Electronics and Electrical Measurements, $36,000,000.
(B) Manufacturing Engineering, $16,000,000.
(C) Chemical Science and Technology, $22,500,000.
(D) Physics, $28,700,000.
(E) Materials Science and Engineering, $39,400,000.
(F) Building and Fire Research, $12,000,000.
(G) Computer Systems, $20,600,000.
(H) Applied Mathematics and Scientific Computing, $6,300,000.
(I) Technology Assistance, $10,800,000.
(J) Research Support Activities, $25,000,000.
(K) Pay Raise, $3,900,000

(2) (A) Of the total of the amounts authorized under paragraph (1), $2,000,000 are authorized only for steel technology.

(B) Of the amount authorized under paragraph (1)(I)—

(i) $500,000 are authorized only for the evaluation of nonenergy-related inventions and related technology extension activities;

(ii) $250,000 are authorized only for Institute participation in the pilot program established under subsection (e); and

(iii) $5,000,000 are authorized only for the Institute's management of the extramural funding programs authorized under section 105.

(C) Of the total amount authorized under paragraph (1)(J), $7,223,000 are authorized only for the technical competence fund.

(3) In addition to the amounts authorized under paragraph (1), there are authorized to be appropriated to the Secretary for fiscal year 1993 $34,800,000 for the renovation and upgrading of the Institute's facilities.

(c) Transfers. (1) Funds may be transferred among the line items listed in subsection (a)(1) and among the line items listed in subsection (b)(1), so long as the net funds transferred to or from any line item do not exceed 10 percent of the amount authorized for that line item in such subsection and the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives are notified in advance of any such transfer.

(2) The Secretary may propose transfers to or from any line item listed in subsection (a)(1) or subsection (b)(1) exceeding 10 percent of the amount authorized for such line item, but such proposed transfer may not be made unless—

(A) a full and complete explanation of any such proposed transfer and the reason therefor are transmitted in writing to the Speaker of the House of Representatives, the President of the Senate, and the appropriate authorizing Committees of the House of Representatives and the Senate, and

(B) 30 calendar days have passed following the transmission of such written explanation.

(d) Relation to Other Authorizations. Except for authorizations provided in the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418; 102 Stat. 1448), the Earthquake Hazards Reduction Act of 1977 (42 U.S.C. 7701 et seq.), and the Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988 (15 U.S.C. 5101 et seq.), this Act contains the complete authorizations of appropriations for the Institute for fiscal years 1992 and 1993. This subsection shall not limit the authority of the Institute to accept funds appropriated to any other Federal agency or to perform work for others.

(e) Pilot Program. Pursuant to the authorizations contained in subsections (a)(1)(I) and (b)(1)(I), the Secretary is authorized to pay the Federal share of the cost of establishing and carrying out a standards assistance pilot program under section 112 of the National Institute of Standards and Technology Authorization Act for Fiscal Year 1989 (15 U.S.C. 272 note). The purpose of the pilot program is to assist a country or countries that have requested assistance from the United States in the development of comprehensive industrial standards by providing the continuous presence of United States personnel on-site for a period of 2 or more years to provide such assistance and by providing, as necessary, additional technical support from within the Institute. Such funds shall be made available for such purpose only to the extent that matching funds are received by the National Institute of Standards and Technology from sources outside the Federal Government.

(f) Construction of Facilities. Section 14 of the National Institute of Standards and Technology Act (15 U.S.C. 278d) is amended by striking "herein:" and all that follows, and inserting in lieu thereof "herein.".

(g) Fire and Building Programs. The fire research and building technology programs of the Institute may be combined for administrative purposes only, and separate budget accounts for fire research and building technology shall be maintained. No later than December 31, 1992, the Secretary, acting through the Director of the Institute, shall report to Congress on the results of the combination, on efforts to preserve the integrity of the fire research and building technology programs, on the long-range basic and applied research plans of the two programs, on procedures for receiving advice on fire and earthquake research priorities from constituencies concerned with public safety, and on the relation between the combined program at the Institute and the United States Fire Administration.

(h) Educational Programs. (1) Section 18 of the National Institute of Standards and Technology Act (15 U.S.C. 278g-1) is amended by striking the period at the end of the first sentence and inserting in lieu thereof ", and to United States citizens for research and technical activities on Institute programs.".

(2) Section 17 of the National Institute of Standards and Technology Act (15 U.S.C. 278g) is amended by adding at the end the following new subsection:

"(d) For any scientific and engineering disciplines for which there is a shortage of suitably qualified and available United States citizens and nationals, the Secretary is authorized to recruit and employ in scientific and engineering fields at the Institute foreign nationals who have been lawfully admitted to the United States for permanent residence under the Immigration and Nationality Act and who intend to become United States citizens. Employment of a person under this paragraph shall not be subject to the provisions of title 5, United States Code, governing employment in the competitive service, or to any prohibition in any other Act against the employment of aliens, or against the payment of compensation to them.".

(i) Core Program Funding. It is the sense of the Congress that the intramural scientific and technical research and services activities of the National Institute of Standards and Technology should share fully in any funding increases provided to the Institute.

SEC. 105. EXTRAMURAL PROGRAMS OF THE INSTITUTE.

(a) Fiscal Year 1992. In addition to any sums otherwise authorized under this Act, there are authorized to be appropriated to the Secretary, to carry out the extramural industrial technology services programs of the Institute created under sections 25, 26, and 28 of the National Institute of Standards and Technology-Act (15 U.S.C. 278k, 278l, and 278n), $127,500,000 for fiscal year 1992, which shall be available for the following line items:

(1) Regional Centers for the Transfer of Manufacturing Technology, $25,000,000.

(2) State Technology Extension Program, $2,500,000.

(3) Advanced Technology Program, $100,000,000.

(b) Fiscal Year 1993. In addition to any sums otherwise authorized under this Act, there are authorized to be appropriated to the Secretary, to carry out the extramural industrial technology services programs of the Institute created under sections 25, 26, and 28 of the National Institute of Standards and Technology Act (15 U.S.C. 278k, 278l, and 278n), $127,500,000 for fiscal year 1993, which shall be available for the following line items:

(1) Regional Centers for the Transfer of Manufacturing Technology and Satellite Manufacturing Centers, $25,000,000.

(2) State Technology Extension Program, $2,500,000.

(3) Advanced Technology Program, $100,000,000.

(c) Limitation. No funds are authorized under this section for any project under the extramural programs of the Institute which have not been competitively reviewed through the merit review processes required by the National Institute of Standards and Technology Act (15 U.S.C. 271 et seq.).

(d) Amendments to Extension Program. Section 5121(b) of the Omnibus Trade and Competitiveness Act of 1988 (15 U.S.C. 278l note) is amended by striking paragraph (5).

(e) Amendments to Extension Activities. (1) Section 25(c)(6) of the National Institute of Standards and Technology Act (15 U.S.C. 278k(c)(6)) is amended by inserting before the period at the end the following: "except for contracts for such specific technology extension or transfer services as may be specified by statute or by the Director".

(2) Section 25(d) of the National Institute of Standards and Technology Act (15 U.S.C. 278k(d)) is amended to read as follows:

"(d) In addition to such sums as may be authorized and appropriated to the Secretary and Director to operate the Centers program, the Secretary and Director also may accept funds from other Federal departments and agencies for the purpose of providing Federal funds to support Centers. Any Center which is supported with funds which originally came from other Federal departments and agencies shall be selected and operated according to the provisions of this section."

(f) Advisory Committee. Section 5142(f) of the Omnibus Trade and Competitiveness Act of 1988 (15 U.S.C. 4632(f)) is amended by striking "and 1990" and inserting in lieu thereof "1990, 1991, 1992, and 1993".

SEC. 110. REPORT ON FACILITIES NEEDS.

By March 1, 1992, the Director of the Institute shall submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a report on what renovations and upgrades of Institute facilities are necessary over the next decade. The report shall include a ranking of facilities needs in order of priority, an estimate of costs, and the Director's plan for meeting these needs.

TITLE II—ADVANCED TECHNOLOGY PROGRAM AMENDMENTS

SEC. 201. EMERGING TECHNOLOGIES RESEARCH AND DEVELOPMENT.

(a) Short Title. This title may be cited as the "Emerging Technologies and Advanced Technology Program Amendments Act of 1991".

(b) Findings and Purposes.

(1) The Congress finds that—

(A) technological innovation and its profitable inclusion in commercial products are critical components of the ability of the United States to raise the living standards of Americans and to compete in world markets;

(B) maintaining viable United States-based high technology industries is vital to both the national security and the economic well-being of the United States;

(C) the Department of Commerce has reported that the United States is losing or losing badly, relative to Japan and Europe, in many important emerging technologies and risks losing much of the $350,000,000,000 United States market and $1,000,000,000,000 world market expected to develop by the year 2000 for products based on emerging technologies;

(D) it is in the national interest for the Federal Government to encourage and, in selected cases, provide limited financial assistance to industry-led private sector efforts to increase research and development in economically critical areas of technology;

(E) joint ventures are a particularly effective and appropriate way to pool resources to conduct research that no single company is likely to undertake but which will create new generic technologies that will benefit an entire industry and the welfare of the Nation;

(F) it is vital that industry within the United States attain a leadership role and capability in development, design, and manufacturing in fields such as high-resolution information systems, advanced manufacturing, and advanced materials; and

(G) the Advanced Technology Program, established under section 28 of the National Institute of Standards and Technology Act (15 U.S.C. 278n), is the appropriate vehicle for the United States Government to provide limited assistance to joint development within the United States of new high technology capabilities in fields such as high-resolution information systems, advanced manufacturing technology, and advanced materials, and can help encourage United States industry to work together on problems of mutual concern.

(2) The purposes of this section are—

(A) to strengthen the Advanced Technology Program created under section 28 of the National Institute of Standards and Technology Act (15 U.S.C. 278n), and to provide improved guidelines for the allocation of Advanced Technology Program funds appropriated under the authorizations contained in section 105 of this Act;

(B) to promote and assist in the development of advanced technologies and the generic application of such technologies to civilian products, processes, and services;

(C) to improve the competitive position of United States industry by supporting industry-led research and development projects in areas of emerging technology which have substantial potential to advance the economic well-being and national security of the United States, such as high-resolution information systems, advanced manufacturing technology, and advanced materials; and

(D) to support projects that range from idea exploration to prototype development and address long-term, high-risk areas of technological research, development, and application that are not otherwise being adequately developed by the private sector, but are likely to yield important benefits to the Nation.

(c) Advanced Technology Program. (1) Section 28(a) of the National Institute of Standards and Technology Act (15 U.S.C. 278n(a)), is amended by adding at the end the following new sentence: "In operating the Program, the Secretary and Director shall, as appropriate, be guided by the findings and recommendations of the Biennial National Critical Technology Reports prepared pursuant to section 603 of the National Science and Technology Policy, Organization, and Priorities Act of 1976 (42 U.S.C. 6683)."

(2) Section 28(b)(1) of the National Institute of Standards and Technology Act (15 U.S.C. 278n(b)(1)), is amended by inserting "industry-led" immediately after "aid".

(3) Section 28(b)(1)(B) of the National Institute of Standards and Technology Act (15 U.S.C. 278n(b)(1)(B)), is amended by inserting "by means of grants, cooperative agreements, or contracts" immediately after "such joint ventures".

(4) Section 28(b)(2) of the National Institute of Standards and Technology Act (15 U.S.C. 278n(b)(2)), is amended to read as follows:

"(2) provide grants to and enter into contracts and cooperative agreements with United States businesses (especially small businesses), provided that emphasis is placed on applying the Institute's research, research techniques, and expertise to those organizations' research programs;".

(5) Section 28(d)(2) of the National Institute of Standards and Technology Act (15 U.S.C. 278n(d)(2)) is amended to read as follows:

"(2) In the case of joint ventures, the Program shall not make an award unless the award will facilitate the formation of a joint venture or the initiation of a new research and development project by an existing joint venture.".

(6) Section 28(d) of the National Institute of Standards and Technology Act (15 U.S.C. 278n(d)(7)) is amended—

(A) by striking paragraph (7);

(B) by redesignating paragraphs (8) and (9) as paragraphs (7) and (8), respectively; and

(C) by adding at the end the following new paragraphs:

"(9) A company shall be eligible to receive financial assistance under this section only if—

"(A) the Secretary finds that the company's participation in the Program would be in the economic interest of the United States, as evidenced by investments in the United States in research, development, and manufacturing (including, for example, the manufacture of major components or subassemblies in the United States); significant contributions to employment in the United States; and agreement with respect to any technology arising from assistance provided under this section to promote the manufacture within the United States of products resulting from that technology (taking into account the goals of promoting the competitiveness of United States industry), and to procure parts and materials from competitive suppliers; and

"(B) either—

"(i) the company is a United States-owned company; or

"(ii) the Secretary finds that the company is incorporated in the United States and has a parent company which is incorporated in a country which affords to United States-owned companies opportunities, comparable to those afforded to any other company, to participate in any joint venture similar to those authorized under this Act; affords to United States-owned companies local investment opportunities comparable to those afforded to any other company; and affords adequate and effective protection for the intellectual property rights of United States-owned companies.

"(10) Grants, contracts, and cooperative assignments under this section shall be designed to support projects which are high risk and which have the potential for eventual substantial widespread commercial application. In order to receive a grant, contract, or cooperative agreement under this section, a research and development entity shall demonstrate to the Secretary the requisite ability in research and technology development and management in the project area in which the grant, contract, or cooperative agreement is being sought.

"(11)(A) Title to any intellectual property arising from assistance provided under this section shall vest in a company or companies incorporated in the United States. The United States may reserve a nonexclusive, nontransferable, irrevocable paid-up license, to have practiced for or on behalf of the United States, in connection with any such intellectual property, but shall not, in the exercise of such license, publicly disclose proprietary information related to the license. Title to any such intellectual property shall not be transferred or passed, except to a company incorporated in the United States, until the expiration of the first patent obtained in connection with such intellectual property.

"(B) For purposes of this paragraph, the term 'intellectual property' means an invention patentable under title 35, United States Code, or any patent on such an invention.

"(C) Nothing in this paragraph shall be construed to prohibit the licensing to any company of intellectual property rights arising from assistance provided under this section."

(7) Section 28(e) of the National Institute of Standards and Technology Act (15 U.S.C. 278n(e)) is amended to read as follows:

"(e) The Secretary may, within 30 days after notice to Congress, suspend a company or joint venture from continued assistance under this section if the Secretary determines that the company, the country of incorporation of the company or a parent company, or the joint venture has failed to satisfy any of the criteria set forth in subsection (d)(9), and that it is in the national interest of the United States to do so."

(8) Section 28 of the National Institute of Standards and Technology Act (15 U.S.C. 278n) is amended by adding at the end the following new subsections:

"(f) When reviewing private sector requests for awards under the Program, and when monitoring the progress of assisted research projects, the Secretary and the Director shall, as appropriate, coordinate with the Secretary of Defense and other senior Federal officials to ensure cooperation and coordination in Federal technology programs and to avoid unnecessary duplication of effort. The Secretary and the Director are authorized to work with the Director of the Office of Science and Technology Policy, the Secretary of Defense, and other appropriate Federal officials to form interagency working groups or special project offices to coordinate Federal technology activities.

"(g) In order to analyze the need for the value of joint ventures and other research projects in specific technical fields, to evaluate any proposal made by a joint venture or company requesting the Secretary's assistance, or to monitor the progress of any joint venture or any company research project which receives Federal funds under the Program, the Secretary, the Under Secretary of Commerce for Technology, and the Director may, notwithstanding any other provision of law, meet with such industry sources as they consider useful and appropriate.

"(h) Up to 10 percent of the funds appropriated for carrying out this section may be used for standards development and technical activities by the Institute in support of the purposes of this section.

"(i) In addition to such sums as may be authorized and appropriated to the Secretary and Director to operate the Program, the Secretary and Director also may accept funds from other Federal departments and agencies for the purpose of providing Federal funds to support awards under the Program. Any Program award which is supported with funds which originally came from other Federal departments and agencies shall be selected and carried out according to the provisions of this section.

"(j) As used in this section—

"(1) the term 'joint venture' means any group of activities, including attempting to make, making, or performing a contract, by two or more persons for the purpose of—

"(A) theoretical analysis, experimentation, or systematic study of phenomena or observable facts;

"(B) the development or testing of basic engineering techniques;

"(C) the extension of investigative finding or theory of a scientific or technical nature into practical application for experimental and demonstration purposes, including the experimental production and testing of models, prototypes, equipment, materials, and processes;

"(D) the collection, exchange, and analysis of research information;

"(E) the production of any product, process, or service; or

"(F) any combination of the purposes specified in subparagraphs (A), (B), (C), (D), and (E), and may include the establishment and operation of facilities for the conducting of research, the conducting of such venture on a protected and proprietary basis, and the prosecuting of applications for patents and the granting of licenses for the results of such venture; and

"(2) the term 'United States-owned company' means a company that has majority ownership or control by individuals who are citizens of the United States."

(d) Effective Date. The amendments in subsection (c) shall take effect immediately upon enactment; however, the amendments shall not apply to applications submitted before the date of enactment of this Act.

(e) Management Costs. Section 2 of the National Institute of Standards and Technology Act (15 U.S.C. 272) is amended by adding at the end thereof the following new subsection:

"(d) In carrying out the extramural funding programs of the Institute, including the programs established under sections 25, 26, and 28 of this Act, the Secretary may retain reasonable amounts of any funds appropriated pursuant to authorizations for these programs in order to pay for the Institute's management of these programs."

(f) Comprehensive Report. The Secretary shall, not later than 4 years after the date of enactment of this Act, submit to each House of the Congress and the President a comprehensive report on the results of the Advanced Technology Program established under section 28 of the National Institute of Standards and Technology Act (15 U.S.C. 278n), including any activities in the areas of high-resolution information systems, advanced manufacturing technology, and advanced materials.

SEC. 303. RESEARCH EQUIPMENT.

Section 11 of the Stevenson-Wydler Technology Innovation Act of 1980 (15 U.S.C. 3710) is amended by adding at the end the following new subsection:

"(i) Research Equipment. The Director of a laboratory, or the head of any Federal agency or department, may give research equipment that is excess to the needs of the laboratory, agency, or department to an educational institution or nonprofit organization for the conduct of technical and scientific education and research activities. Title of ownership shall transfer with a gift under the section."

TITLE V—STUDIES AND REPORTS

SEC. 507. NATIONAL QUALITY COUNCIL.

(a) Establishment and Functions. There is established a National Quality Council (hereafter in this section referred to as the "Council")...

(b) Membership. The Council shall consist of not less than 17 or more than 20 members, appointed by the Secretary. Members shall include ...

(9) one representative from the National Institute of Standards and Technology; ...

(12) one representative from the Foundation for the Malcolm Baldrige National Quality Award...

* * * * *

October 26, 1992, 106 Stat. 3410 (Public Law 102-522—102 Congress, 2d session) Fire Administration Authorization Act of 1992.

Public Law 102-522

AN ACT

To authorize appropriations for activities under the Federal Fire Prevention and Control Act of 1974, and for other purposes.

SEC. 106. (a) (106 Stat. 3416) Amendment.—"

(d) Regulations.—

The Administrator of General Services, in cooperation with the United States Fire Administration, the National Institute of Standards and Technology, and the Department of Defense, within 2 years after the date of enactment of this section, shall promulgate regulations to further define the term 'equivalent level of safety', and shall, to the extent practicable, base those regulations on nationally recognized codes.

* * * * *

APPENDIX B

HISTORIES OF THE NATIONAL BUREAU OF STANDARDS

1. War Work of the Bureau of Standards. Miscellaneous Publication No. 46

Anonymous
US Government Printing Office, 1921
299 pp.

Table of Contents (There are no chapters, only topics listed in alphabetical order. No Bureau employees' names are mentioned.)

Aeronautic instruments; Aeronautic power plants; Aircraft construction; Aircraft materials; Aircraft (miscellaneous); Airplane dopes; Balloon gases; Calibration of testing machines; Chemical investigations (miscellaneous); Chromatic camouflage and chromatically concealed insignia; Coke-oven investigations; Concrete and cement; Concrete ships; Electric batteries; Electric blasting apparatus; Electric tractors and trucks; Electrical inductance method for location of metal bodies; Gages, precision; Illuminating engineering; Inks and ink powders; Invisible signaling; Invisible writing, means for the detection of; Leather; Magnetic investigations; Manilla rope; Medical supplies; Metallurgical investigations; Physical tests of metals and metal structures; Natural-gas investigations; Optical glass and optical instruments; Ordnance; Paper; Photography; Protective coatings; Publications and information; Radio communications; Radiometry; Radium; Rope, manila; Rubber; Safety standards for military industrial establishments; Searchlights; Sound-ranging apparatus; Sounds transmitted through the earth; Submarine detection; Telephone problems; Testing machines, calibration of; Textiles; Timepieces; Toloul recovery; Wheels, investigation of artillery, truck, and airplane; X-rays.

No **Index** was included with the text.

2. The Bureau of Standards: Its History, Activities, and Organization

Gustavus A. Weber
Johns Hopkins Press, 1925
299 pp.

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3. NBS War Research—The National Bureau of Standards in World War II

Lyman J. Briggs, Director Emeritus, NBS
U.S. Government Printing Office, September 1949
187 pp.

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Appendix

Scientific and Technical Divisions and Sections (2 pp.)
No **Index** was included with the text.

4. The Story of Standards

John Perry
Funk & Wagnalls, 1955
271 pp.

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5. Measures For Progress: A History of the National Bureau of Standards

Rexmond C. Cochrane

NBS Miscellaneous Publication 275, US Government Printing Office, 1966.

703 pp.

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Bibliography (10 pp.)

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6. Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards

Wilbert F. Snyder and Charles L. Bragaw

NBS Special Publication 555, US Government Printing Office, October 1986

842 pp.

Table of Contents

7. A Unique Institution: The National Bureau of Standards, 1950-1969

Elio Passaglia, with Karma A. Beal
NBS Special Publication 925, US Government Printing Office, 1999
822 pp.

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APPENDIX C

NBS/NIST IN THE FEDERAL ADMINISTRATION

Supervisory Chain Above NBS. In this appendix, we list Executive departmental officials who exercised supervisory authority over NBS/NIST. Beginning with the appointment of Craig R. Scheaffer as Assistant Secretary of Commerce for Domestic Affairs under Sinclair Weeks, the Secretary of Commerce frequently appointed a subordinate who bore such a responsibility.

The dates of service of NBS/NIST directors include periods served as Acting Director by Briggs, Astin, Ambler, and Kammer.

UNITED STATES PRESIDENTS	DEPARTMENTAL OFFICIALS	NBS/NIST DIRECTORS
William McKinley 1897-1901	Lyman J. Gage Secretary of the Treasury 1897-1902	
	Leslie M. Shaw Secretary of the Treasury 1902-1907	
	George B. Cortelyou Secretary of Commerce and Labor 1903-1904	
Theodore Roosevelt 1901-1909	Victor H. Metcalf Secretary of Commerce and Labor 1904-1906	
	Oscar S. Strauss Secretary of Commerce and Labor 1906-1909	Samuel W. Stratton 1901-1922
William H. Taft 1909-1913	Charles Nagel Secretary of Commerce and Labor 1909-1913	
	William C. Redfield Secretary of Commerce 1913-1919	
Woodrow Wilson 1913-1921	Joshua W. Alexander Secretary of Commerce 1919-1921	
Warren G. Harding 1921-1923	Herbert C. Hoover Secretary of Commerce 1921-1928	
Calvin Coolidge 1923-1929	William F. Whiting Secretary of Commerce 1928-1929	George K. Burgess 1923-1932
Herbert C. Hoover 1929-1933	Robert P. Lamont Secretary of Commerce 1929-1932	
	Roy D. Chapin Secretary of Commerce 1932-1933	
	Daniel C. Roper Secretary of Commerce 1933-1938	Lyman J. Briggs 1932-1945
	Harry L. Hopkins Secretary of Commerce 1938-1940	
Franklin D. Roosevelt 1933-1945	Jesse H. Jones Secretary of Commerce 1940-1945	
	Henry A. Wallace Secretary of Commerce 1945-46	

UNITED STATES PRESIDENTS	DEPARTMENTAL OFFICIALS	NBS/NIST DIRECTORS
Harry S Truman 1945-1953	Henry A. Wallace Secretary of Commerce 1945-1946 W. Averell Harriman Secretary of Commerce 1946-1948 Charles W. Sawyer Secretary of Commerce 1948-1953	Edward U. Condon 1945-1951
Dwight D. Eisenhower 1953-1961	Sinclair Weeks Secretary of Commerce 1953-1958 Craig R. Scheaffer Assistant Secretary of Commerce for Domestic Affairs 1953 James C. Worthy Assistant Secretary of Commerce for Domestic Affairs 1953 Lewis L. Strauss Secretary of Commerce 1958-1959 Frederick H. Mueller Secretary of Commerce 1959-1961 Carl F. Oechsle Assistant Secretary of Commerce for Domestic Affairs 1960	Allen V. Astin 1951-1969
John F. Kennedy 1961-1963	Luther H. Hodges Secretary of Commerce 1961-1965 Hickman Price, Jr. Assistant Secretary of Commerce for Domestic Affairs 1961 J. Herbert Hollomon Assistant Secretary of Commerce for Science and Technology 1962-1967	
Lyndon B. Johnson 1963-1969	John T. Connor Secretary of Commerce 1965-1967 J. Herbert Hollomon Assistant Secretary of Commerce for Science and Technology 1962-1967 Alexander B. Trowbridge Secretary of Commerce 1967-1968 John S. Kincaid Assistant Secretary of Commerce for Science and Technology 1967-1968 Cyrus R. Smith Secretary of Commerce 1968-1969	
	Maurice H. Stans Secretary of Commerce 1969-1972	

UNITED STATES PRESIDENTS	DEPARTMENTAL OFFICIALS	NBS/NIST DIRECTORS
Richard M. Nixon 1969-1974	Maurice H. Stans Secretary of Commerce 1969-1972 Myron Tribus Assistant Secretary of Commerce for Science and Technology 1969-1970 Rocco C. Siciliano Under Secretary of Commerce 1970-1971 James H. Wakelin, Jr. Assistant Secretary of Commerce for Science and Technology 1971-1972 Peter G. Peterson Secretary of Commerce 1972-1973 James H. Wakelin, Jr. Assistant Secretary of Commerce for Science and Technology 1971-1972	Lewis M. Branscomb 1969-1972
Gerald R. Ford 1974-1977	Frederick B. Dent Secretary of Commerce 1973-1975 Betsy Ancker-Johnson Assistant Secretary of Commerce for Science and Technology 1973-1977	Richard W. Roberts 1973-1975
	Rogers C. B. Morton Secretary of Commerce 1975-1976 James A. Baker, III Under Secretary of Commerce 1975-1976 Betsy Ancker-Johnson Assistant Secretary of Commerce for Science and Technology 1973-1977 Elliot L. Richardson Secretary of Commerce 1976-1977 Edward O. Vetter Under Secretary of Commerce 1976-1977 Betsy Ancker-Johnson Assistant Secretary of Commerce for Science and Technology 1973-1977	Ernest Ambler 1975-1989

UNITED STATES PRESIDENTS	DEPARTMENTAL OFFICIALS	NBS/NIST DIRECTORS
Jimmy Carter 1977-1981	Juanita Kreps Secretary of Commerce 1977-1979 Sidney Harman Under Secretary of Commerce 1977-1978 Jordan J. Baruch Assistant Secretary of Commerce for Science and Technology 1977-1980 Luther H. Hodges, Jr. Under Secretary of Commerce 1979 Philip M. Klutznick Secretary of Commerce 1980-1981 Luther H. Hodges, Jr. Deputy Secretary of Commerce 1980 Jordan J. Baruch Assistant Secretary of Commerce for Productivity, Technology, and Innovation 1980	Ernest Ambler 1975-1989
Ronald W. Reagan 1981-1989	Malcolm Baldrige Secretary of Commerce 1981-1987 C. William Verity, Jr. Secretary of Commerce 1987-1989	
George W. Bush 1989-1993	Robert A. Mosbacher Secretary of Commerce 1989-1992 Barbara H. Franklin Secretary of Commerce 1992-1993 Robert M. White Under Secretary of Commerce for Technology 1991-1993	John W. Lyons 1990-1993
William J. Clinton 1993-2001	Ronald H. Brown Secretary of Commerce 1993-1996 Mary L. Good Under Secretary of Commerce for Technology 1993-1997 Michael Kantor Secretary of Commerce 1996-1997 Mary L. Good Under Secretary of Commerce for Technology 1993-1997	Arati Prabhakar 1993-1997
	William M. Daley Secretary of Commerce 1997- Cheryl L. Shavers Under Secretary of Commerce for Technology 1999-	Raymond G. Kammer 1997-

APPENDIX D

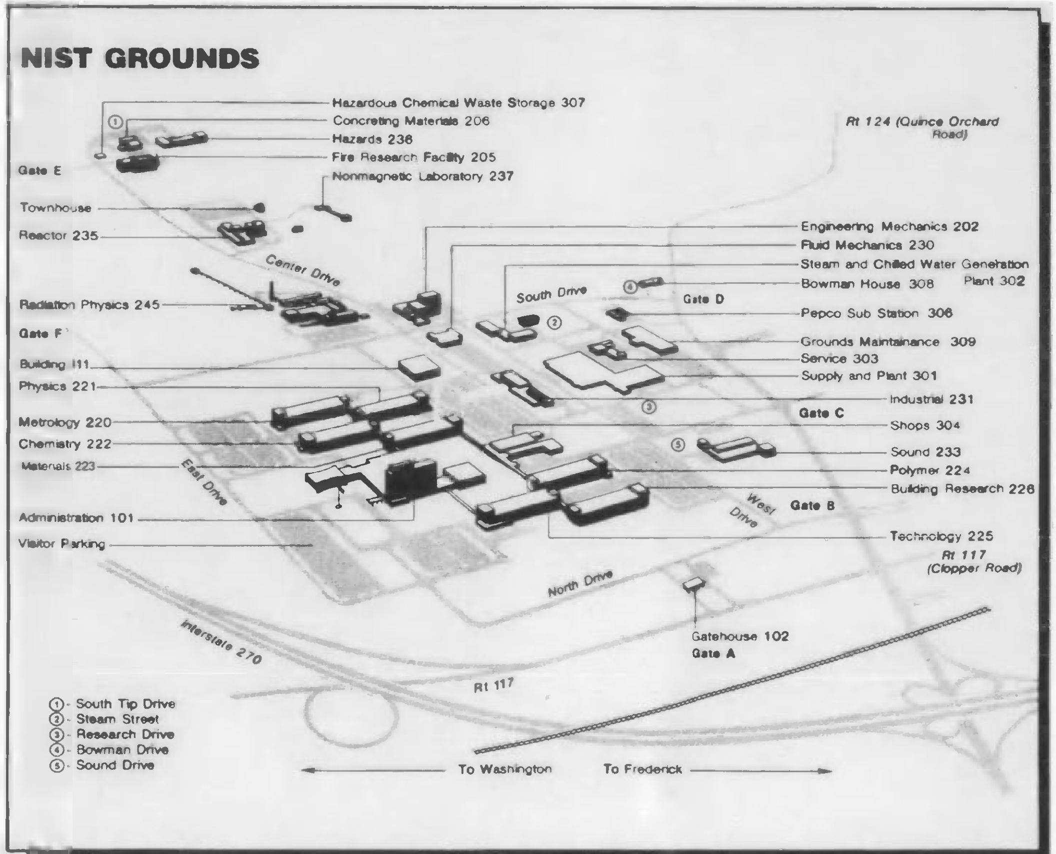
SITE INFORMATION AND MAPS
GAITHERSBURG AND BOULDER

CONSTRUCTION SCHEDULE FOR BUILDINGS AND SERVICE STRUCTURES ON THE NBS/NIST GAITHERSBURG SITE AS OF 1990

Building Number	Building Name	Date Begun	Date Completed	Date Occupied**	Area*
101	Administration	6-18-62	7-12-65	7-12-65	202.4
102	Gate House	5-1-69	3-1-70	2-19-70	.1
202	Engineering Mechanics	7-19-61	10-1-63	6-1-63	46.1
205	Fire Research	10-1-73	10-1-75	4-15-74	12.5
206	Concreting Materials	3-1-66	3-1-68	3-1-68	5.4
220	Metrology	8-21-63	2-14-66	2-14-66	109.1
221	Physics	8-21-63	3-28-66	3-28-66	111.5
222	Chemistry	8-21-63	2-28-66	2-28-66	79.5
223	Materials	8-21-63	4-27-66	4-27-66	78.1
224	Polymers	8-21-63	6-6-66	6-6-66	78.6
225	Instrumentation	8-21-63	8-3-66	8-3-66	104.6
226	Building Research	8-21-63	10-3-66	9-8-66	64.4
230	Fluid Mechanics	6-1-67	6-1-69	6-1-69	50.1
231	Industrial	2-8-66	2-8-68	2-8-68	40.6
233	Sound	9-20-65	2-27-68	2-27-68	21.2
235	Reactor	4-25-63	8-23-65	8-23-65	61.1
236	Hazards	4-15-66	4-15-68	5-15-68	6.5
237, 238	Non-Magnetic	6-3-64	2-14-68	2-14-68	4.4
245	Radiation	6-18-62	8-20-65	4-15-64	88.1
301	Supply and Plant	6-18-62	10-15-64	10-15-64	103.8
302	Steam and Chilled Water Generating Plant	7-19-61	7-21-64	4-1-63	27.6
303	Service	6-18-62	5-4-64	5-4-64	12.3
304	Instrument	6-18-62	12-4-64	12-4-64	53.6
305	Cooling Tower	7-19-61	7-21-64	------	------
306	Electrical Substation	7-19-61	1-2-64	4-1-63	------
307	Chemical Waste	12-1-70	5-1-71	1-6-72	.3
308	Bowman House	~1952	~1953	5-15-69	3.8
309	Grounds	10-1-74	10-1-76	4-24-75	8.9
310	Hazardous Materials Storage	10-1-86	1-1-87	------	------
411	Temporary Relocatable Facility	1-1-89	2-1-90	9-1-89	8.0
Total available area*					1,382.5

Area, Main Gaithersburg site = 575 acres. Acquired 1958 to 1970.
Area, Nike site = 13.7 acres. Acquired 1975.
Notes: Dates are coded month-day-year.
*Units: Thousands of square feet.
**Date occupied by NBS scientists.

Source: Plant Division, NIST, February 6, 1990


NIST GROUNDS
Hazardous Chemical Waste Storage 307
Concreting Materials 206
Hazards 236
Fire Research Facility 205
Nonmagnetic Laboratory 237
Gate E
Townhouse
Reactor 235
Center Drive
Radiation Physics 245
Gate F
Building 111
Physics 221
Metrology 220
Chemistry 222
Materials 223
East Drive
Administration 101
Visitor Parking
Rt 124 (Quince Orchard Road)
Engineering Mechanics 202
Fluid Mechanics 230
Steam and Chilled Water Generation Plant 302
Bowman House 308
South Drive
Gate D
Pepco Sub Station 306
Grounds Maintainance 309
Service 303
Supply and Plant 301
Industrial 231
Gate C
Shops 304
Sound 233
Polymer 224
Building Research 226
West Drive
Gate B
Technology 225
Rt 117 (Clopper Road)
North Drive
Gatehouse 102
Gate A
Interstate 270
Rt 117
1 - South Tip Drive
2 - Steam Street
3 - Research Drive
4 - Bowman Drive
5 - Sound Drive
To Washington
To Frederick

BUILDINGS AND STRUCTURES OF THE NATIONAL BUREAU OF STANDARDS

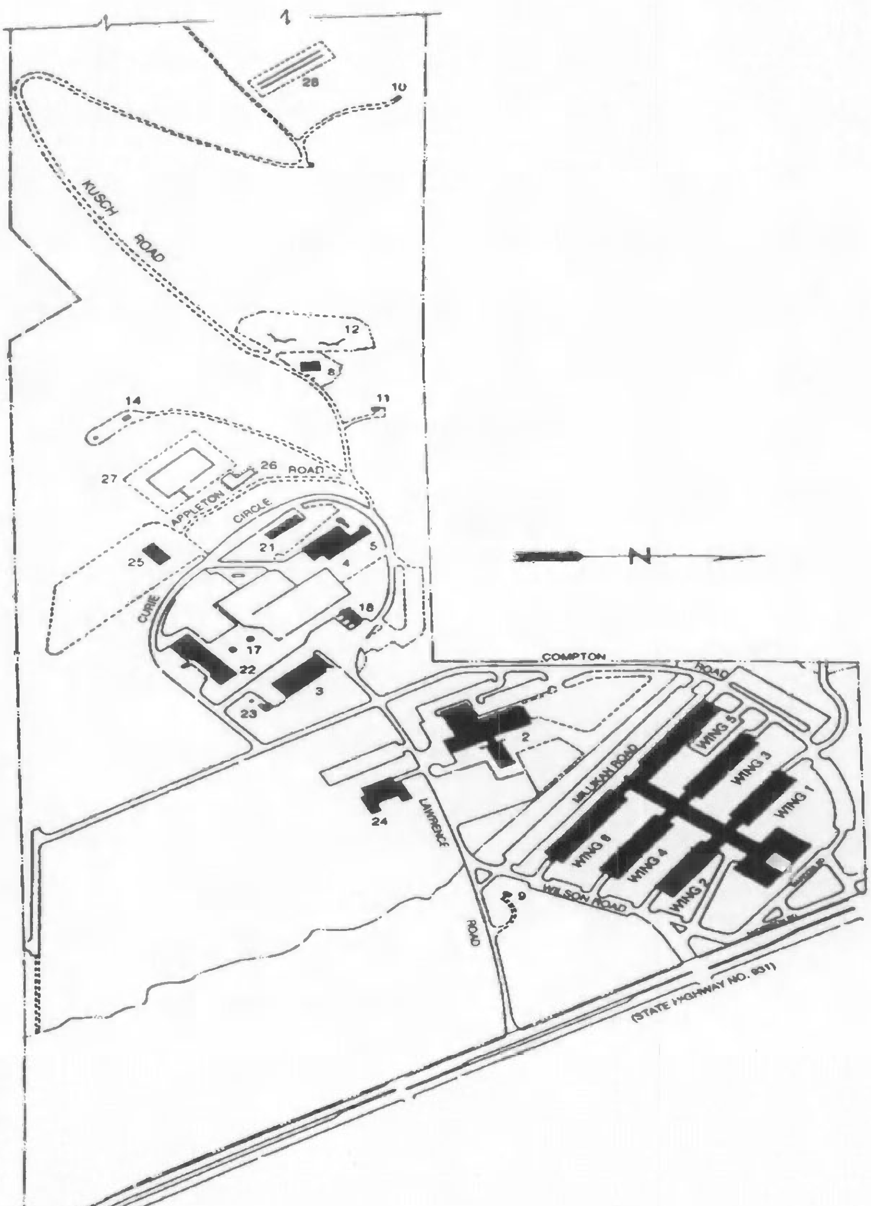
BOULDER, COLORADO

1970

Building*	Name	Date (in operation)	Assignable Square Feet
B1	Radio Building: Library, Auditorium, Center Spine, Wing 1, Wing 2, Wing 3, Wing 4	1954	200,257
B1	Wing 5	1962	77,928
B1	Wing 6	1959	26,000
B2	Cryogenics, South and North Half	1952	45,702
B2	Cryogenics, Wing "B"	1962	9,800
B3	Liquefier	1952	20,024
B4	Camco	1951	15,403
B5	Heavy Equipment	1951	2,850
B8	Cryogenic Mesa Test Site	1953	2,400
B9	Gas Meter	1958	312
B10	Green Mountain Antenna Building	1958-1973	209
B11	Vertical Incidence	1958	408
B14	Field Strength Calibration	1958	278
B17	Hydrogen Storage Tanks		
B18	Tube Tanks (Hydrogen) Storage		
B21	Maintenance Garage	1963	3,968
B22	Warehouse	1964	17,280
B23	Cooling Tower	1957-1989	312
B24	Plasma Physics[1]	1967	27,328
B25	North Shop	1966	3,200
B26	Ground Scanner Site		
B27	High Frequency Field Site		
B28	Microwave Antenna Range		
TOTAL			453,659

* Building numbers appear on site map, next page
Main Site Land: 217 acres
Date Acquired: June 14, 1950

[1] Used by the Environmental Science Services Administration.



KUSCH ROAD
APPLETON ROAD
CIRCLE
CURIE
COMPTON ROAD
MILLIKAN ROAD
WILSON ROAD
LAWRENCE ROAD
(STATE HIGHWAY NO. 831)
WING 1
WING 2
WING 3
WING 4
WING 5
WING 6
N

APPENDIX E

NBS/NIST STAFF, 1901-1999

The accompanying graph shows the growth (and decline!) of the staff of NBS/NIST over the first century of its existence. The personnel statistic most readily available over that period was "total staff," a term that often, but not always, included the following types of workers:

- Full-time permanent employees of NBS/NIST.
- Part-time paid employees, including summer students and other student-program paid personnel, intermittent employees, and temporary employees.
- Postdoctoral Research Associates.
- Paid consultants.
- Industrial Research Associates.
- Guest Workers, both American and foreign.

The chart shows three major peaks in NBS employment, and three declines as well. The peaks reflected intense participation by the Bureau in technical work connected with World War I (1914-1919), World War II (1939-1945), and the Cold War that followed WW II. Declines in NBS employment occurred during the Great Depression of 1929-1939, as a result of transferring to the Department of Defense in 1954 the wartime Bureau programs in proximity fuze research and guided missile research, and, from 1965 to 1985, accompanying a nation-wide weakening in support for scientific research.

It is clear that, despite the many changes wrought in 1988 by Public Law 100-418, the transition from NBS to NIST had no substantial impact on the overall staffing level of the agency.

Available data on full-time permanent employment at NBS/NIST are shown by the lower curves on the chart. In June 1968, a fairly typical year, *NBS Special Publication 308* contained the following breakdown of NBS staff:

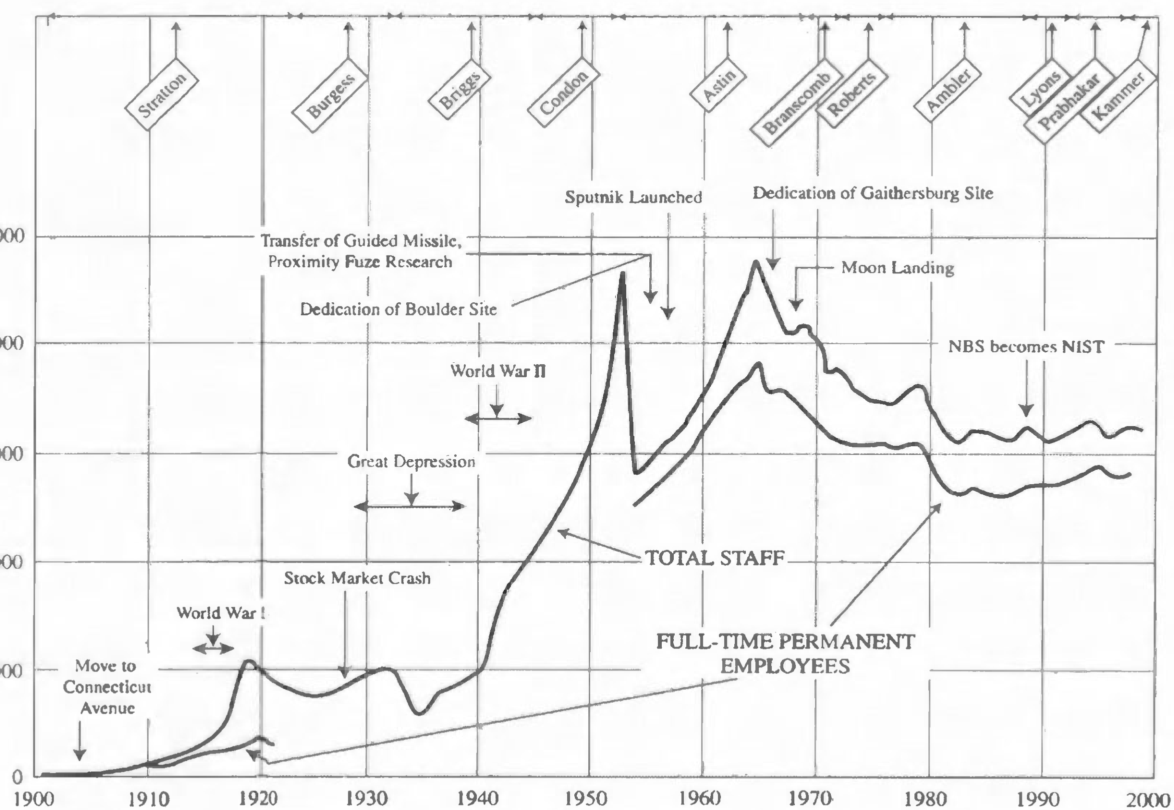
- Full-time permanent, Gaithersburg, including postdoctorals: 2,939.
- Full-time permanent, Boulder, including postdoctorals: 580.
- Other paid staff, Gaithersburg: 305.
- Other paid staff, Boulder: 48.
- Research associates and guest workers, Gaithersburg: 131.
- Research associates and guest workers, Boulder: 16.

Physicists comprised the largest single component of the Bureau professional staff in 1968, numbering 509. Chemists and engineers numbered 279 and 261, respectively. There were 56 mathematicians and 133 professionals of other types. The total number of staff members holding post-graduate degrees—1,238—represented nearly one-third of the total paid staff of NBS.

Also indicated on the graph are the periods of service of the 11 Directors of NBS/NIST and the dates of historical events that had significant impacts on the agency.

Sources: Susan Makar, Office of Information Services. Gail K. Ehrlich, Program Office.

NBS/NIST STAFF 1901-1999



APPENDIX F

NBS/NIST POSTDOCTORAL RESEARCH ASSOCIATES, 1968-1993

Associates were selected by panels of the National Academy of Science and the National Academy of Engineering. The program was administered by the National Research Council.

Name	University	NBS/NIST Advisor
1968		
Donald W. Alderman	Cornell U.	Robert J. Mahler
Michael J. Bielefeld	U. of Pennsylvania	Jon Spijkerman
Edith F. Borie	U. of North Carolina	Leonard Maximon
Arnold M. Denenstein	U. of Pennsylvania	Chester H. Page
Gabriel L. Epstein	U. of California/Berkeley	Joseph Reader
Benjamin Gibson	Stanford U.	Michael Danos
Roger A. Hegstrom	Harvard U.	Jon H. Shirley and Richard P. Reed
John W. Knoeck	Iowa State U.	John K. Taylor
Hassell M. Ledbetter	U. of Illinois	Richard P. Reed
William R. Ott	U. of Pittsburgh	Wolfgang L. Wiese
Stephen J. Pierce	U. of California/Santa Barbara	Morris Newman
LeRoy W. Schroeder	Northwestern U.	John J. Rush
Stuart K. Searles	U. of Alberta, Canada	Pierre Ausloos
Stanley E. Stokowski	Stanford U.	Ludwig H. Grabner
Donald D. Thornton	Syracuse U.	Billy W. Mangum
Edward F. Zalewski	U. of Chicago	Richard A. Keller
1969		
Gordon W. Day	U. of Illinois	Lawrence M. Matarrese
William L. Greer	U. of Chicago	Robert J. Rubin
Larry Handy	U. of Wisconsin	Frederick E. Brinckman
Max A. Haney	Rice U.	Thomas C. Farrar
William M. Haynes	U. of Virginia	Dwain E. Diller
Elizabeth J. Jacob	U. of Michigan	David R. Lide, Jr.
Paul S. Julienne	U. of North Carolina	Frederick H. Mies
Ernest G. Kessler	U. of Wisconsin	William C. Martin
Carl A. Kocher	Massachusetts Institute of Technology	Richard H. Kropschot
David E. Kranbuehl	U. of Wisconsin	Peter H. Verdier
Michael J. Kurylo, III	Catholic U. of America	Walter Braun
Russell L. Merris	U. of California/Santa Barbara	Morris Newman
William C. Mitchell	Washington University	Baldwin Robertson
Rogers W. Redding	Vanderbilt U.	Jon T. Hougen
Gregory J. Rosasco	Fordham U.	Hans P.R. Frederikse
Isaac C. Sanchez	U. of Delaware	Edmund A. DiMarzio
Carl C. Semmelroth	U. of Michigan	Isadore Nimeroff
Kenneth G. Sharp	Rice U.	Thomas D. Coyle
Selden L. Stewart	U. of Texas	Stephen J. Tauber
1970		
Gerald B. Cohen	Carnegie Mellon U.	F. Cecil Brenner
Nordulf W.G. Debye	Cornell U.	James R. Devoe and Melvin Linzer

Douglas L. Franzen	U. of Minnesota	Harold S. Boyne
John W. Gramlich	U. of Hawaii	I. Lynus Barnes
William M. Haynes	U. of Virginia	Dwain E. Diller
Elizabeth J. Jacob	U. of Michigan	David R. Lide, Jr.
Andrew Kaldor	Cornell U.	Arthur G. Maki, Jr.
George E. Kelly	Northwestern U.	Max Klein and Johanna M. H. Levelt Sengers
Donald R. Lehman	George Washington U.	Michael Danos
Frank J. Lovas	U. of California/Berkeley	David R. Lide, Jr.
Michael A. Marchetti	Georgetown U.	Frederick H. Mies
Bruce W. Morrissey	Rensselaer Polytechnic Institute	Robert R. Stromberg
Donald W. Regula	Wayne State U.	Gershon Kulin
Michael W. Schuyler	Indiana U.	Richard A. Keller
Mark E. Sheingorn	U. of Wisconsin	Morris Newman
Carroll A. Shelton	U. of Pittsburgh	Stanley Block
Siegfried Treu	U. of Pittsburgh	Charles T. Meadow and Thomas N. Pyke
1971		
John H. Albers	Massachusetts Institute of Technology	Raymond D. Mountain
George H. Atkinson	Indiana U.	Richard A. Keller
Frank P. Billingsley	U. of Virginia	Morris Krauss
Marvin Bishop	Columbia U.	Edmund A. DiMarzio
Harry S. Camarda	Columbia U.	Harry H. Landon
James F. Ely	Indiana U.	Dwain E. Diller
Clark A. Hamilton	U. of Rochester	Robert A. Kamper and Kenneth M. Evenson
Camden R. Hubbard	Iowa State U.	Floyd A. Mauer
Charles E. Hughes	Pennsylvania State U.	Charles T. Meadow
Joel F. Liebman	Princeton U.	Thomas D. Coyle
James J. Murphy	U. of Illinois	William R. Dodge
Robert C. Reno	Brandeis U.	Lawrence H. Bennett
Raymond C. Sansing	Southern Methodist U.	Joan R. Rosenblatt
Emil Simiu	Princeton U.	Edward O. Pfrang
Michael B. Simmonds	U. of California/Irvine	James E. Zimmerman
Arthur D. Yaghjian	Brown U.	David M. Kerns
Gerald A. Zerdy	U. of Maryland	Martin Greenspan
1972		
Robert E. Berger	Johns Hopkins U.	Melvin R. Meyerson
William J. Boettinger	Johns Hopkins U.	Robert L. Parker
Lawrence S. Cardman	Yale U.	Samuel Penner
Richard S. Davis	U. of Maryland	Barry N. Taylor and Vincent E. Bower
John R. Eyler	Stanford U.	L. Wayne Sieck
James C. Holste	Iowa State U.	Ray Radebaugh
Charles R. Johnson	California Institute of Technolgy	Morris Newman
James R. Lyerla, Jr.	U. of Utah	Dennis A. Torchia
George W. Mulholland	Cornell U.	Raymond W. Mountain
Edwin R. Naimon	U. of Illinois	Richard P. Reed
Charles A. Nelson	U. of Maryland	Sydney Meshkov
Dale E. Newbury	U. of Oxford, England	Harvey Yakowitz
James D. Olson	Michigan State U.	Howard J.M. Hanley
Michael G. Reimer	U. of Pennsylvania	Philip D. Lafleur

Michael S. Sorem	Stanford U.	Donald A. Jennings
Carl F. Stubenrauch	U. of Michigan	Ramon C. Baird
Daniel M. Sweger	American U.	John C. Travis and James J. Rhyne
E. Clayton Teague	North Texas State U.	Russell D. Young
Tommy C. Tong	U. of Michigan	David M. Kerns
James C. Tsang	Massachusetts Institute of Technology	Hans P. R. Frederikse
1973		
Edwin D. Cehelnik	Pennsylvania State U.	Oscar Menis
Frank O. Clark	U. of Virginia	Donald R. Johnson
Harry J. Dewey	U. of Utah	Richard D. Deslattes
Robert E. Drullinger	Columbia U.	Earl W. Smith
John W. Ekin	Cornell U.	Robert L. Powell
Barry L. Farmer	Case Western Reserve U.	Ronald K. Eby
John P. Ferraris	John Hopkins U.	Martin G. Broadhurst
Edwin R. Fuller, Jr.	U. of Illinois	Sheldon M. Wiederhorn
Robert J. Hocken	State U. of New York/Stony Brook	Johanna M. H. Levelt Sengers
David E. Laughlin	Massachusetts Institute of Technology	Robert L. Parker
Larry L. Lucas	U. of California/Davis	Wilfrid B. Mann
Jon J. McCarthy	Iowa State U.	Evans V. Hayward
Evelyn M. Rockar	U. of California/Riverside	Herbert S. Bennett and Richard A. Forman
Douglas R. Shier	U. of London, England	Alan J. Goldman
Allen R. Siedle	Indiana U.	Thomas D. Coyle
James J. Snyder	State U. of New York/Stony Brook	Peter L. Bender
Marjorie L. Stein	Princeton U.	Burton H. Colvin and Alan J. Goldman
Roger L. Stockbauer	U. of Chicago	Henry M. Rosenstock
Nicholas Vagelatos	U. of Michigan	John J. Rush
Bernard A. Weinstein	Brown U.	Richard A. Forman
William F. Weston	U. of Illinois	Richard P. Reed
John T. Yue	Stanford U.	J. William Gadzuk
1974		
Robert S. Butler	Pennsylvania State U.	Paul F. Roth
Ilan S. Chabay	U. of Chicago	Wayne A. Cassatt, Jr.
Robert B. Feinberg	U. of Wisconsin	Morris Newman
Ronald F. Fleming	U. of Michigan	Ivan G. Schroder
Robert B. Green	Ohio U.	John C. Travis
Joseph W. Haus, Jr.	Catholic U. of America	Harold J. Raveche
Jan F. Herbst	Cornell U.	J. William Gadzuk
Warren W. Johnson	Rutgers U.	Michael C. Jones
Nell D. Lerner	Brown U.	Martin Greenspan
Rodney A. McKee	U. of Texas	John R. Manning
Eric B. Miller	Duke U.	....
Harry Morgan	Howard U.	....
John A. Mucha	U. of Pittsburgh	Kenneth A. Evenson
George E. Parris	Georgia Institute of Technology	Frederick E. Brinckman
Richard J. Pearson, Jr.	Harvard U.	Frank J. Lovas
Bruce J. Pletka	Case Western Reserve U.	Sheldon M. Wiederhorn
David T. Read	U. of Illinois	Richard P. Reed
William L. Rowan	U. of Texas	Wolfgang L. Wiese

Peter J. Slater	U. of Iowa	Alan J. Goldman
Samuel R. Stein	Stanford U.	Helmut Hellwig
John B. West	U. of California/Santa Barbara	Jerry P. Eaton
1975		
Dennis M. Breiter	U. of Maryland	Kurt F. J. Heinrich
Jason Gait	Weslayan U.	Hans J. Oser
Karla L. Hoffman	George Washington U.	Alan J. Goldman
Duane R. Kirklin	U. of Maryland	Stanley Abramowitz
William F. Koch	Iowa State U.	Robert J. Cutkosky
David S. Malkus	Boston U.	Jeffrey T. Fong
Ronald G. Manning	U. of California/Davis	John T. Herron
Herbert A. Robinson	U. of California/Santa Barbara	Morris Newman
Paul M. Skarstad	Cornell U.	Robert S. Roth
Richard D. Suenram	U. of Kansas	Donald R. Johnson
1976		
Bruce J. Ackerson	U. of Colorado	Gerald C. Straty
Dennis R. Dietz	Washington U.	Melvin Linzer
Edward T. Dressler	American U.	James S. O'Connell
Pashang Esfandiari	Catholic U. of America	Johanna M. H. Levelt Sengers
David D. Evans	Harvard U.	Clayton Huggett
Robert M. Garvey	Duke U.	Helmut Hellwig
David W. Goodman	U. of Texas	John T. Yates, Jr.
Robert R. Greenberg	U. of Maryland	Philip D. Lafleur
Dane L. Harwood	U. of California/Los Angeles	Edward B. Magrab
Robert H. Havemann	U. of Colorado	Robert J. Phelan, Jr.
Frank P. Higgins	U. of Denver	Melvin Linzer
Richard L. Kautz	Massachusetts Institute of Technology	Donald G. McDonald
Marvin D. Kemple	U. of Illinois	Billy W. Mangum
Eric C. Kintner	U. of Edinburgh, Scotland	----
Donald C. Knauss	Northern Illinois U.	----
John R. Long	Ohio State U.	Thomas D. Coyle
Richard I. Martinez	U. of California/Los Angeles	John T. Herron
Gregory B. McKenna	U. of Utah	Elliott Kearsley
Ronald G. Munro	U. of Oregon	Herbert S. Bennett
Robert S. Polvani	U. of Connecticut	Arthur W. Ruff
John F. Rabolt	Southern Illinois U.	Bruno Fanconi
James C. Rainwater	U. of Colorado	Howard J.M. Hanley
Garry L. Ritter	U. of North Carolina	Lloyd A. Currie
David M. Shold	U. of Chicago	Pierre Ausloos
John A. Small	U. of Maryland	Wayne A. Cassatt, Jr.
Terry R. Todd	Pennsylvania State U.	William B. Olson
William N. Unerti	U. of Wisconsin	Robert J. Celotta and Daniel T. Pierce
1977		
James E. Bond	Yale U	Charles D. Bowman
Brian M. Ditchek	Northwestern U.	Arthur W. Ruff
Flonnie Dowell	Georgetown U.	Edmund A. DiMarzio
Michael C. Drake	Pennsylvania State U.	John W. Hastie
Brett I. Dunlap	Johns Hopkins U.	J. William Gadzuk
William L. Earl	U. of California/Berkeley	David L. VanderHart
Richard J. Fields	U. of Cambridge, England	Jeffrey T. Fong
Gordon E. Fish	U. of Illinois	Lydon J. Swartzendruber

Steven W. Haan	U. of Maryland	Raymond D. Mountain
Robert H. Kagann	U. of Colorado	Merrill M. Hessel
Steven B. Kaplan	U. of Pennsylvania	James E. Zimmerman
George M. Keiser	Duke U.	James E. Faller
Edward F. Kelley	Montana State U.	Robert E. Hebner
James F. Lawrence	U. of Washington	Alan J. Goldman
Joanne L. Murray	U. of Maryland	Donald H. Tsai
David R. Myers	U. of Illinois	W. Murray Bullis
Stephen J. Norton	Stanford U.	George Birnbaum
Timothy A. Reinhold	Virginia Polytechnic Institute	Robert A. Crist, Jr.
Peter Roitman	Princeton U.	W. Murray Bullis
Richard J. Saykally	U. of Wisconsin	Kenneth M. Evenson
Stephan J. Weeks	U. of Florida	John C. Travis
1978		
Martin E. Batts	U. of Michigan	Emil Simiu
Steven L. Baughcum	Harvard U.	Stephen R. Leone
James C. Bergquist	U. of Colorado	Richard L. Barger
Stephen E. Bialkowski	U. of Utah	John C. Stephenson
Robert J. Cava	Massachusetts Institute of Technology	Robert S. Roth
Richard R. Cavanagh	Harvard U.	John T. Yates, Jr.
Lawrence M. Doane	U. of Connecticut	Richard A. Durst
Theodore D. Doiron	Duke U.	Sandra C. Greer
Keith R. Eberhardt	Johns Hopkins U.	Joan R. Rosenblatt
James T. Hall	U. of California/Santa Barbara	Robert J. Soulen, Jr.
John C. Hamilton	Cornell U.	Daniel T. Pierce
Gary G. Hembree	Arizona State U.	Dennis A. Swyt
Jeffrey A. Hinkley	U. of Wisconsin	Donald M. Novotny
John B. Ings	Rutgers U.	Geoffrey Frohnsdorff
David J. Lohse	U. of Illinois	Isaac C. Sanchez
Jay F. Marchiando	Iowa State U.	Dennis A. Swyt
Duane P. Matthees	U. of Maryland	Robert Schaffer
John E. Orban	Ohio State U.	Joan R. Rosenblatt
Anastasi Papathanasis	U. of California/Davis	Harold E. Marshall
John C. Schaefer	U. of Chicago	....
Alexander Scheeline	U. of Wisconsin	James R. Devoe
Charles F. Scribner	U. of Michigan	Edgar V. Leyendecker
Richard D. Starr	U. of Illinois	Evans V. Hayward
Stephen M. Younger	U. of Maryland	Andrew W. Weiss
1979		
John G. Abbott	Duke U.	Melvin Linzer
James R. Bethin	U. of Illinois	Alan D. Franklin
Robert E. Botto	Michigan State U.	Bruce Coxon
Michael W. Cromar	U. of Oregon	Donald B. Sullivan
Michael J. Dipirro	State U. of New York/Buffalo	Craig T. Van Degrift
Charles Fenimore	U. of California/Berkeley	Ronald G. Rehm
Vincent J. Fratello	Harvard U.	Charles Tilford
Ronald B. Goldfarb	Colorado State U.	Frederick R. Fickett
John E. Goldsmith	Stanford U.	Stephen J. Smith
Ronald L. Greene	U. of Colorado	Larry J. Roszman
Gregory L. Griffin	Princeton U.	John T. Yates, Jr.
Arthur J. Grimley	Cornell U.	John C. Stephenson
Stephen J. Grotzinger	Rensselaer Polytechnic U.	Christoph J. Witzgall
Virginia K. Hardman	U. of Missouri	James J. Rhyne

Wayne M. Itano	Harvard U.	David J. Wineland
Harold D. Ladouceur	Purdue U.	Jon T. Hougen
Frank Magnotta	U. of California/Berkeley	Stephen R. Leone
Terry A. Michalske	Alfred U.	Sheldon M. Wiederhorn
Gregory J. Olson	Montana State U.	Warren P. Iverson
Ronald W. Rendell	U. of California/Santa Barbara	David R. Penn
Thomas M. Shay	Colorado State U.	James J. Snyder
David A. Vanbaak	Harvard U.	John L. Hall
Deborah Van Vechten	U. of Maryland	Robert J. Soulen, Jr.
Richard F. Wormsbecher	U. of California/Santa Barbara	Frank J. Lovas

1980

Garnett W. Bryant	Indiana U.	J. William Gadzuk
Eldon D. Case	Iowa State U.	Edwin R. Fuller, Jr.
Robert M. Davidson	U. of California/San Francisco	Bruce Coxon
Robert W. Gerlach	U. of Washington	Lloyd A. Currie
David A. Goodman	U. of California/Berkeley	John R. Cuthill
Richard E. Hanig	Purdue U.	Robert B. Schwartz
George J. Havrilla	West Virginia U.	John C. Travis
Wendell T. Hill III	Stanford U.	Thomas B. Lucatorto
William C. Johnson	Michigan Technological U.	John W. Cahn
Douglas W. Jones	U. of Arizona	Wolfgang L. Wiese
Ronald D. Kriz	Virginia Polytech Institute	Maurice B. Kasen
Kathryn A. Lee	City College of New York	Donald R. Durst
Gabriel G. Lombardi	Harvard U.	James R. Roberts
Michael Martinka	Pennsylvania State U.	Alan J. Melmed
John H. Miller	U. of Virginia	Kermit C. Smyth
Boyce M. Morrison, Jr.	Pennsylvania State U.	John T. Herron
Paul M. Nachman	U. of Chicago	John L. Hall
Clifford R. Pollock	Rice U.	Kenneth M. Evenson
John S. Provan	Cornell U.	Christoph J. Witzgall
Dorothy A. Reed	Princeton U.	Emil Simiu
Wade T. Rogers	U. of Colorado	Robert J. Celotta
Stephen Semancik	Brown U.	Theodore E. Madey
Robert Stahlbush	Cornell U.	Richard A. Forman
Carl S. Weiss	Washington State U.	Frederick E. Brinckman

1981

Eric J. Amis	U. of Wisconsin	Charles C. Han
Tim D. Andreadis	U. of Maryland	Joseph Fine
Michael R. Berman	U. of California/Berkeley	John C. Stephenson
Joseph A. Blazy	U. of Chicago	John C. Stephenson
Thomas J. Bruno	Georgetown U.	Howard J.M. Hanley
Charles W. Clark	U. of Chicago	Andrew W. Weiss
Dale L. Doering	Washington State U.	Theodore E. Madey
David A. Dolson	Indiana U.	Stephen R. Leone
Robert G. Downing	U. of Missouri	Dale E. Newbury
Michael A. Duncan	Rice U.	Stephen R. Leone
Jeffrey R. Fox	Cornell U.	Robert D. McCarty
Michael H. Kelley	U. of Texas	Robert J. Celotta
Walter R. Lampert	U. of Utah	Alfons Weber
Timothy P. Lodge	U. of Wisconsin	Charles C. Han
Joseph V. Minervini	Massachusetts Institute of Technology	Donald B. Sullivan

Donald R. Myers	Drexel U.	James S. Albus
David J. Nesbitt	U. of Colorado	John L. Hall
Steven R. Nutt	U. of Virginia	Arthur W. Ruff
John V. Prodan	Colorado State U.	William D. Phillips
Steven R. Ray	Princeton U.	Hratch G. Semerjian
Mark A. Zumberge	U. of Colorado	Judah Levine
1982		
John J. Bollinger	Harvard U.	David J. Wineland
Daniel G. Friend	U. of Colorado	James C. Rainwater
Vicky L. Himes	Catholic U. of America	Antonio Santoro
Anna E. McHale	Massachusetts Institute of Technology	Robert S. Roth
Andrew K. Persily	Princeton U.	Richard A. Grot
Kenneth W. Pratt	Iowa State U.	William F. Koch
Gregory A. Reynolds	Virginia Polytechnic Institute	Baldwin Robertson
Stephen B. Sears	U. of North Carolina	Frederick H. Mies
Stephen H. Southworth	U. of California/Berkeley	Albert C. Parr
Brian R. Stallard	Cornell U.	Stanley L. Shapiro
1983		
Robert F. Berg	U. of Florida	Michael R. Moldover
John E. Blendell	Massachusetts Institute of Technology	Taki Negas
Benjamin P. Burton	State U. of New York/Stony Brook	Taki Negas
Michael P. Casassa	California Institute of Technology	Richard C. Cavanagh
Christopher L. Cromer	U. of Southern California	Thomas B. Lucatorto
Robert A. Dragoset	U. of Virginia	E. Clayton Teague
Charles S. Feigerle	U. of Colorado	Robert J. Celotta
William E. Fogle	U. of California/Berkeley	Robert J. Soulen, Jr.
Joe P. Foley	U. of Florida	Willie E. May
Katherine G. Frase	U. of Pennsylvania	Taki Negas
John J. Horvath	U. of Florida	Hratch G. Semerjian
John K. Hoskins	U. of California/Irvine	James E. Faller
Eugene A. Imhoff	Cornell U.	Michael I. Bell
George J. Jelatis	Pennsylvania State U.	Michael R. Moldover
George R. Jones	U. of Virginia	Edwin R. Williams
Richard L. Kurtz	Yale U.	Roger L. Stockbauer
Pui K. Lam	U. of California/Berkeley	Steven M. Girvin
Martin K. Ligare	Columbia U.	Daniel E. Kelleher
Thomas P. Lockhart	California Institute of Technology	Frederick E. Brinckman
William F. Manders	U. of Maryland	David L. VanderHart
David A. Mantell	Yale U.	Richard R. Cavanagh
Ronald H. Ono	State U. of New York/Stony Brook	Richard E. Harris
Neal D. Shinn	Massachusetts Institute of Technology	Theodore E. Madey
Terrence J. Udovic	U. of Wisconsin	Theodore E. Madey
Michael J. Wax	U. of California/Berkeley	Theodore E. Madey
Indrek S. Wichman	Princeton U.	Takashi Kashiwagi
Perry F. Wilson	U. of Colorado	Mark T. Ma
Lawrence A. Woltz	U. of Florida	Larry J. Roszman
1984		
Regina E. Bonanno	U. of Maryland	Thomas B. Lucatorto
Charles E. Bouldin	U. of Washington	Richard A. Forman
Robert M. Briber	U. of Massachusetts	Fred A. Khoury
David F. Cox	U. of Florida	Stephen Semancik

Brian E. Eaton	U. of Colorado	James F. Ely
Carol A. Handwerker	Massachusetts Institute of Technology	John R. Manning
Jonathan E. Hardis	U. of Chicago	Albert C. Parr
Edwin J. Heilweil	U. of Pennsylvania	John C. Stephenson
Paul G. Jasien	U. of Illinois	Walter J. Stevens
John W. Keller	U. of Maryland	Robert P. Madden
Kenneth R. Leopold	Harvard U.	Kenneth M. Evenson
Joe W. Magee	Rice U.	Thomas M. Flynn
Howard T. Mayfield	U. of Alabama	Stephen N. Chesler
Alan L. Migdall	Massachusetts Institute of Technology	William D. Phillips
Bruce R. Miller	U. of Texas	Andre Deprit
John M. Moreland	U. of California/Santa Barbara	John W. Ekin
Barry F. Muhlfelder	U. of Rochester	Donald G. McDonald
Glen C. Nielson	U. of Chicago	Harold J. Raveche
Richard E. Preston	Princeton U.	Hratch G. Semerjian
Phillip D. Szuromi	California Institute of Technology	Theodore E. Madey
Philip H. Taylor	Pennsylvania State U.	Kermit C. Smyth
George A. Thompson	New York City Technical College	Alfons Weber
R.M. Verkouteren	Purdue U.	Lloyd A. Currie
Karna J. Wahlstrand	Harvard U.	Martin G. Broadhurst
Anne M. Woodward	Yale U.	John C. Stephenson
Timothy J. Wozniak	Indiana U.	Harry S. Hertz

1985

Penrose C. Albright	U. of Maryland	Johanna M. H. Levelt Sengers
Jacques G. Amar	Temple U.	Harold J. Raveche
Michael G. Ambrose	Cleveland State U.	Bruce Coxon
Donald R. Burgess, Jr.	Northwestern U.	Richard C. Cavanagh
Thomas W. Coyle	Massachusetts Institute of Technology	Sheldon M. Wiederhorn
Paula M. Davidson	State U. of New York/Stony Brook	John W. Hastie
Jon W. Erickson	Brown U.	Stephen Semancik
Ross W. Erwin	U. of Maryland	James J. Rhyne
Gerald T. Fraser	Harvard U.	Alan S. Pine
Sarah L. Gilbert	U. of Michigan	David J. Wineland
Stephen A. Hackney	U. of Virginia	John W. Cahn
Robert W. Harrison	Yale U.	Alexander Wlodawer
Marcia L. Huber	Colorado School of Mines	James F. Ely
Randall G. Hulet	Massachusetts Institute of Technology	David J. Wineland
Bettye C. Johnson	Harvard U.	Thomas B. Lucatorto
Russell D. Johnson	U. of Minnesota	Jeffrey W. Hudgens
Robert K. Jones	Indiana U.	Robert J. Celotta
Leonard E. Klebanoff	U. of California/Berkeley	Daniel T. Pierce
Lindsay B. Lloyd	U. of Utah	Alan Fried
Jeffrey A. Marqusee	Massachusetts Institute of Technology	Isaac C. Sanchez
David L. Moffat	U. of Wisconsin	Joanne L. Murray
David H. Roach	Case Western Reserve U.	Brian R. Lawn
Craig A. Rottman	U. of Illinois	John W. Cahn
Joseph V. Rutkowski	Dartmouth College	Richard C. Gann
Damian Shea	U. of Maryland	William A. MacCrehan
Daniel A. Steigerwald	Carnegie Mellon U.	William F. Egelhoff, Jr.
Peter L. Swanson	U. of Colorado	Stephen W. Freiman
Richard J. Walker	State U. of New York/Stony Brook	Larry J. Moore

1986

Richard T. Brundage	U. of Wisconsin	Michael I. Bell
Diane S. Bushee	Northeastern U.	Paul J. Paulsen
John C. Clark	U. of Minnesota	Charles C. Han
James P. Cline	Alfred U.	Camden R. Hubbard
Michael J. Deweert	U. of Notre Dame	Steven M. Girvin
Teresa B. Fryberger	Northwestern U.	Stephen Semancik
Phillip L. Gould	Massachusetts Institute of Technology	William D. Phillips
Allen L. Johnson	U. of California/Berkeley	Theodore E. Madey
John H. Shibata	U. of Washington	Francis W. Wang
David M. Sonnenfroth	U. of Rochester	Stephen R. Leone

1987

Steven A. Buntin	U. of Minnesota	Richard R. Cavanagh
Laurence D. Coyne	U. of Massachusetts	Wen-Li Wu
Jack F. Douglas	U. of Chicago	Charles C. Han
Phillip N. First	U. of Illinois	Robert J. Celotta
Dale W. Fitting	U. of Tennessee	Ronald D. Kriz
Bernard R. Foy	Massachusetts Institute of Technology	John C. Stephenson
David R. Garmer	Pennsylvania State U.	Walter J. Stevens
Mark W. Hart	Rice U.	Daniel T. Pierce
Stephen A. Joyce	Massachusetts Institute of Technology	Theodore E. Madey
Susan T. Krueger	U. of Maryland	Gregory J. Olson
Alan I. Nakatani	U. of Connecticut	Charles C. Han
David D. Nelson	Harvard U.	David J. Nesbitt
Vicki G. Niesen	Colorado School of Mines	Lloyd A. Weber
Margo D. Palmieri	Iowa State U.	William F. Koch
Stephen M. Penn	U. of Wisconsin	Stephen R. Leone
Joseph E. Sauvageau	State U. of New York/Stony Brook	Donald G. McDonald
Thomas W. Stafford, Jr.	U. of Arizona	Lloyd A. Currie
Richard N. Watts	U. of Michigan	William D. Phillips
Christoph I. Westbrook	U. of Michigan	William D. Phillips

1988

Muhammad Arif	U. of Missouri	Geoffrey L. Greene
John D. Beckerle	Massachusetts Institute of Technology	Richard R. Cavanagh
Lucien N. Brush	Carnegie Mellon U.	Geoffrey B. McFadden
David V. Dearden	California Institute of Technology	Jeffrey W. Hudgens
Richard L. Dubs	California Institute of Technology	Paul S. Julienne
Roger A. Edberg	Australian National U.	Howard J.M. Hanley
Stephen J. Fischer	Washington State U.	Bernard J. McCaffrey
John D. Gillaspy	Harvard U.	Daniel E. Kelleher
Allan H. Harvey	U. of California/Berkeley	Johanna M. H. Levelt Sengers
Daniel J. Heinzen	Massachusetts Institute of Technology	James C. Bergquist
Martin E. Huber	Stanford U.	Michael W. Cromar
Catheryn L. Jackson	U. of Connecticut	Gregory B. McKenna
Gregg M. Jankowski	Michigan Technical U.	Richard J. Fields
Peter J. Martin	Massachusetts Institute of Technology	John L. Hall
Christopher W. Meyer	U. of California/Santa Barbara	Michael R. Moldover
Paul J. Miller	Yale U.	Stephen R. Leone
Bruce T. Murray	U. of Arizona	Geoffrey B. McFadden
Lee J. Richter	Cornell U.	Richard R. Cavanagh
Jamal A. Sandarusi	Colorado School of Mines	William M. Haynes

Ray E. Snyder	Stanford U.	Hratch G. Semerjian
Mark A. Sobolewski	Stanford U.	Stephen Semancik
Carol E. Tanner	U. of California/Berkeley	William D. Phillips
Thomas J. Walsh	U. of Oregon	Richard E. Harris
Lloyd J. Whitman	Cornell U.	Theodore E. Madey
Joseph C. Woicik	Stanford U.	Michael I. Bell
1989		
Stephen A. Angel	U. of Colorado	John C. Stephenson
Julie A. Borchers	U. of Illinois	James J. Rhyne
W.C. Carter	U. of California/Berkeley	Edwin R. Fuller, Jr.
Edith S. Grabbe	U. of North Carolina	Dennis J. Reeder
Dennis W. Hair	U. of Southern California	Charles C. Han
Steven R. Lorentz	U. of Oklahoma	Michael H. Kelley
Christopher M. Lovejoy	U. of Colorado	Stephen R. Leone
James P. Moran	U. of Virginia	Dale A. Meyn
Thomas S. Norton	Princeton U.	Kermit C. Smyth
Mark G. Raizen	U. of Texas	David J. Wineland
Allison C Sandlin	U. of Alabama	Robert J. Schaefer
Weston L. Tew, Jr.	U. of Colorado	Edwin R. Williams
Dean A. Waldow	U. of Wisconsin	Charles C. Han
James R. Zurio	Carnegie Mellon U.	Cary Presser
1990		
Michael R. Frey	U. of North Carolina	James J. Filiben
David T. Gallagher	U. of Texas	Gary L. Gilliland
Alexis Grabbe	U. of North Carolina	Brian R. Lawn
Kristian P. Helmerson	Massachusetts Institute of Technology	William D. Phillips
Joanne R. Hetzler	Massachusetts Institute of Technology	David S. King
Erik K. Hobbie	U. of Minnesota	Charles C. Han
David C. Humm	U. of Illinois	Charles W. Clark
John A. Kramar	California Institute of Technology	E. Clayton Teague
Curtis G. Lindsay	Virginia Polytechnic Institute	Robert S. Roth
Robert D. McMichael	Ohio State U.	Lawrence H. Bennett
Nhan V. Nguyen	Pennsylvania State U.	David G. Seiler
Eric C. Palm	Texas A&M U.	Craig T. Van Degrift
Cecilia D. Richards	U. of California/Irvine	William M. Pitts
Stephen E. Russek	Cornell U.	John W. Ekin
Deborah G. Sauder	Johns Hopkins U.	John C. Stephenson
William M. Snow	Harvard U.	Geoffrey L. Greene
Kevin A. Sparks	Massachusetts Institute of Technology	James F. Ely
Paul G. Strupp	Northwestern U.	Stephen R. Leone
Lorraine E. Twerdok	Johns Hopkins U.	Michael G. Simic
Barry J. Wythoff	U. of New Hampshire	Lloyd A. Currie
Gregory A. Zimmerli	Pennsylvania State U.	Richard E. Harris
1991		
David S. Alavi	U. of Pittsburgh	Michael P. Casassa
Richard J. Braun	Northwestern U.	Geoffrey B. McFadden
Michael J. Chester	U. of Pennsylvania	Terrence J. Jach
Neil D. Clarke	Massachusetts Institute of Technology	Gary L. Gilliland
Mark D. Dadmun	U. of Massachusetts	Charles C. Han
Thomas P. Dougherty	Massachusetts Institute of Technology	Edwin J. Heilweil
Edward A. Early	U. of California/San Diego	Alan F. Clark

Ofodike A. Ezekoye	U. of California/Berkeley	Howard R. Baum
Timothy J. Foecke	U. of Minnesota	Robb M. Thomson
Jonathan M. Gilligan	Yale U.	David J. Wineland
Lori S. Goldner	U. of California/Santa Barbara	William D. Phillips
Joel E. Harrington	U. of Wisconsin	Kermit C. Smyth
Cynthia D. Holcomb	Cornell U.	William M. Haynes
Karl K. Irikura	California Institute of Technology	Jeffrey W. Hudgens
Mark T. Kief	Pennsylvania State U.	William F. Egelhoff, Jr.
William E. Luecke	Cornell U.	Sheldon M. Wiederhorn
Kevin B. McGrattan	New York U.	Ronald G. Rehm
Thomas H. McWaid	U. of California/Santa Barbara	Theodore V. Vorburger
Thomas R. O'Brian	U. of Wisconsin	Thomas B. Lucatorto
William J. Orts	U. of Toronto, Canada	Wen-Li Wu
Brooks H. Pate	Princeton U.	Gerald T. Fraser
Gregory E. Poirier	U. of Texas	Stephen Semancik
Martin E. Poitzsch	Harvard U.	John J. Bollinger
Jack L. Robertson	U. of Houston	John J. Rush
Peter A. Rosenthal	Stanford U.	Ronald H. Ono
Russell V. Smilgys	U. of Colorado	Richard L. Kurtz
Michael R. Winchester	Clemson U.	Gregory C. Turk

1992

Carmela C. Amato	Rensselaer Polytechnic Institute	Michael R. Zachariah
Anne M. Andrews	U. of Michigan	Gerald T. Fraser
John R. Berger	U. of Maryland	David T. Read
Jeffrey L. Brum	Tulane U.	Jeffrey W. Hudgens
David M. Bunk	Texas A&M U.	Michael J. Welch
Mun Y. Choi	Princeton U.	Anthony Hamins
Mark W. Coffee	New York U.	Ronald B. Goldfarb
Michael Collison	U. of Michigan	Michael J. Tarlov
Andrew D. Gavrin	Johns Hopkins U.	Michael H. Kelley
James A. Given	Boston U.	Johanna M. H. Levelt Sengers
Steven R. Jefferts	U. of Colorado	David J. Wineland
Alan T. Johnson	Harvard U.	John M. Martinis
Daniel Josell	Harvard U.	Carol A. Handwerker
John J. Kasianowicz	State U. of New York/Stony Brook	Baldwin Robertson
Christopher R. Monroe	U. of Colorado	James C. Bergquist
Janet F. Morrison	American U.	William A. MacCrehan
Warren L. Nachlis	U. of Massachusetts	Charles C. Han
Steven H. Page	Brigham Young U.	Stephen A. Wise
David F. Plusquellic	U. of Pittsburgh	David J. Nesbitt
Laura P. Ratliff	U. of Virginia	Paul D. Lett
Joseph P. Rice	U. of Illinois	David A. Rudman
Jonathan M. Richardson	Harvard U.	Geoffrey L. Greene
Barbara A. Sanborn	State U. of New York/Stony Brook	Herbert S. Bennett
Thaddeus Tarpey	Indiana U.	Dominic F. Vecchia
John H. Van Zanten	U. of California/Los Angeles	Wen-Li Wu
Roger D. Van Zee	U. of California/Berkeley	John C. Stephenson

1993

Levent Acar	Ohio State U.	James S. Albus
David T. Anderson	Dartmouth College	David J. Nesbitt
Philip J. Austin	U. of Michigan	Takashi Kashiwagi
Amy S. Barton	Princeton U.	David J. Wineland

Dennis E. Brown	Stanford U.	David M. Gilliam
Gregg P. Bryant	Purdue U.	David S. King
Jeffrey W. Bullard	U. of California/Berkeley	Edward J. Garboczi
Brent D. Butler	Northwestern U.	Howard J.M. Hanley
Sean M. Casey	U. of Minnesota	Stephen R. Leone
Kevin W. Cassel	Lehigh U.	Ronald G. Rehm
Lance D. Cooley	U. of Wisconsin	Robert N. Goldberg
Donald C. Degroot	Northwestern U.	David A. Rudman
Ivan H. Deutsch	U. of California/Berkeley	William D. Phillips
Joseph A. Dura	U. of Illinois	Charles F. Majkrzak
Sharon C. Glotzer	Boston U.	Edmund A. DiMarzio
William T. Grubbs	Duke U.	Edwin J. Heilweil
Leonard A. Hayden	Oregon State U.	Roger B. Marks
Lowell P. Howard	U. of Warwick, England	E. Clayton Teague
Arthur W. Johnson	Yale U.	William M. Pitts
Robert R. Keller	U. of Minnesota	David T. Read
William D. Lee	U. of Texas	Robert E. Drullinger
Mary L. Lewis	U. of Wyoming	Anne L. Plant
James E. Maslar	U. of Illinois	Michael R. Zachariah
Brian K. McMillin	Stanford U.	Michael R. Zachariah
Eric S. Meyer	Harvard U.	Wolfgang L. Wiese
Dmitry Reznik	U. of Illinois	Daniel A. Neumann
Curt A. Richter	Yale U.	David G. Seiler
Andrew R. Roosen	Rutgers U.	John W. Cahn
Peter N. Saeta	Harvard U.	Alan C. Gallagher
Christopher R. Shaddix	Princeton U.	Kermit C. Smyth
Ping-Shine Shaw	Columbia U.	Richard D. Deslattes
Mark G. Vangel	Harvard U.	Keith R. Eberhardt
Elizabeth Widom	U. of California/Santa Cruz	Robert D. Vocke, Jr.
Dennis C. Winkler	U. of Maryland	Dale E. Newbury
Brian D. Wladkowski	Stanford U.	Walter J. Stevens

Sources:

1. *National Research Council Directory of Resident Research Associates, 1959-1995, (Washington, DC: National Academy Press, 1996),* 740 pp. [Author's note: Some of the information in this source was incomplete or inaccurate.]
2. *NBS Standard* (Official employee bulletin).
3. *NBS Technical News Bulletin* and *NBS Dimensions.*
4. Personal inquiry by Diane Cunningham, NIST Reference Librarian.

APPENDIX G

SCIENTIFIC AWARDS GIVEN BY THE DEPARTMENT OF COMMERCE AND NBS/NIST TO STAFF MEMBERS, 1968-1993

The Arthur S. Flemming Award, established in 1948, honored unusually meritorious work in either science or administration by federal employees under the age of 40. The award was sponsored by the Washington Junior Chamber of Commerce.

The Gold Medal, established in 1949, was the highest honor conferred upon an employee by the Department of Commerce. It was bestowed for distinguished achievements of major significance to the Department or to the Nation.

The Federal Woman's Award, established in 1961, honored outstanding contributions by female Federal employees to major government programs, and recognized unusual examples of personal leadership, judgment, integrity, and dedication.

The Samuel Wesley Stratton Award was created by NBS in 1962 to recognize unusually significant research contributions to science or engineering that merited the acclaim of the scientific world and supported NBS/NIST objectives.

The Edward Bennett Rosa Award, established by NBS in 1964, recognized outstanding achievements in the development of meaningful and significant standards of practice in the measurement field.

The Edward Uhler Condon Award was given by NBS, beginning in 1974, to recognize distinguished achievements in written exposition in science or technology.

The Applied Research Award, established by NBS in 1975, recognized superior achievement in the practical application of the results of scientific or engineering research.

The Measurement Services Award was established by NBS in 1980 to recognize outstanding achievement in calibration and related measurement areas by NBS employees.

The Allen V. Astin Measurement Science Award, first given by NBS in 1984, recognized outstanding achievement in the advancement of measurement science or in the delivery of measurement services.

The William P. Slichter Award, established by NIST in 1992, recognized outstanding achievements by NIST staff in building or strengthening ties between NIST and industry. The award was named as a memorial to William P. Slichter, Executive Director, Materials Science and Engineering Division, AT&T Bell Laboratories, who served on the first NIST Visiting Committee for Advanced Technology.

1968
Gold Medal Awards—
Louis Costrell
Henry J. Kostkowski
Lawrence M. Kushner
David R. Lide, Jr.
Kurt E. Shuler
Group:
Carl O. Muehlhause, Harry H. Landon, Jr., Robert S. Carter.

Stratton Award—David R. Lide, Jr.
Rosa Award—W. Wayne Meinke

National Civil Service League, Career Service Award—Lewis M. Branscomb

1969
Flemming Award—Richard D. Deslattes

Gold Medal Awards—
John A. Bennett
Daniel V. DeSimone
Vernon H. Dibleler
John L. Hall
Samuel Penner
Bourdon F. Scribner

1970
Gold Medal Awards—
Alan D. Franklin
Joseph Hilsenrath
Donald A. Jennings
Malcolm W. Jensen
Walter Koidan
Group:
    Marilyn E. Jacox and Dolphus E. Milligan
Group:
    Gordon H. Dunn, Lee J. Kieffer, Stephen J. Smith.

Stratton Award—Robert P. Madden

Rosa Award—Paul R. Achenbach

International Astronomical Union, Special Award; naming of moon craters after NBS scientists—William W. Coblentz (1873-1962; tenure at NBS, 1905-45); J. Howard Dellinger (1886-1962; tenure at NBS, 1907-48); Hugh L. Dryden (1898-1965; tenure at NBS, 1918-47); Nicholas E. Golovin (1912-69; tenure at NBS 1949-58); William F. Meggers (1888-1966; tenure at NBS 1914-58); Paul W. Merrill (1887-1961; tenure at NBS, 1916-18).

1971
Gold Medal Awards—
Lawrence H. Bennett
Martin J. Berger
Bascom W. Birmingham
Arthur A. Maryott
W. Wayne Meinke
John B. Wachtman
Wolfgang L. Wiese
Group:
    Everett G. Fuller, Evans V. Hayward

Federal Woman's Award—Joan R. Rosenblatt

Stratton Awards—
Group:
    Richard L. Barger, John L. Hall
Group:
    John I. Lauritzen, Elio Passaglia, Edmund DiMarzio.

Rosa Award—Judson C. French

1972
Gold Medal Awards—
Ruth M. Davis
Myron G. Domsitz
Jerome Kruger
James R. McNesby
Lewis V. Spencer

Federal Woman's Award—Ruth M. Davis

Stratton Award—Kenneth M. Evenson

Rosa Award—Emanuel Horowitz

1973
Gold Medal Awards—
Wolfgang K. Haller
David M. Kerns
John I. Lauritzen
John Mandel
Hideo Okabe

Federal Woman's Award—Marilyn E. Jacox

Stratton Award—
Group:
    Marilyn E. Jacox and Dolphus E. Milligan

Rosa Award—Henry J. Kostkowski

Rockefeller Public Service Award—Ruth M. Davis

National Aeronautics and Space Administration, Special Awards—
NASA Exceptional Scientific Achievement Medal for Apollo missions 11, 14, 15—James E. Faller
NASA Exceptional Scientific Achievement Medal for Lunar Ranging Experiment—
Group:
    James E. Faller, Peter L. Bender

1974
Flemming Award—David G. Hummer

Gold Medal Awards—
Ernest M. Levin
James E. Skillington, Jr.
Group;
    Stanley Block, Gasper J. Piermarini.
Group:
    Richard L. Barger, Bruce L. Danielson, Gordon W. Day, Kenneth M. Evenson, John L. Hall, F. Russell Petersen, Joseph S. Wells.

Stratton Award—Richard D. Deslattes

Rosa Award—John K. Taylor

Condon Award—Russell D. Young

1975

Gold Medal Awards—
Paul R. Achenbach
James A. Barnes
Gerhard M. Brauer
Donald G. Fletcher
Emanuel Horowitz
Philip S. Klebanoff
Melvin R. Meyerson
Edward J. Prosen
John A. Simpson
F. Karl Willenbrock
James R. Wright
Group;
Robert A. Kamper, James E. Zimmerman.

Stratton Award—John B. Wachtman, Jr.

Rosa Award—William C. Cullen

Condon Award—Johanna M.H. Levelt Sengers

Applied Research Award—Dicky D. Davis

1976

Gold Medal Awards—
Pierre J. Ausloos
J. Paul Cali
James M. Cassel
Alan J. Goldman
Alexander F. Robertson
Joan R. Rosenblatt
Group:
Glenn F. Engen, Cletus A. Hoer

Federal Woman's Award—Evans V. Hayward

Stratton Award—
Group:
James W. Lightbody, Samuel Penner.

Rosa Award—J. Paul Cali

Condon Award—
Group:
Ralph P. Hudson, Harvey Marshak, Robert J. Soulen, Jr., Donald B. Utton.

Applied Research Award—Gregory J. Rosasco

1977

Flemming Award—Donald R. Johnson

Gold Medal Awards—
Margarete Ehrlich
Alan C. Gallagher
John T. Hall
Melvin Linzer
John W. Lyons
Donald D. Wagman
Group:
Donald R. Johnson, Frank J. Lovas.

Stratton Award—Sheldon M. Wiederhorn

Rosa Award—Wilfrid B. Mann

Condon Award—Robert A. Kamper

Applied Research Award—Anthony J. Barbera

President's Award for Distinguished Federal Civilian Service—Ernest Ambler

National Civil Service League, Career Service Award—Ruth M. Davis

1978

Gold Medal Awards—
Walter Braun
Thomas D. Coyle
Judson C. French
Kurt F.J. Heinrich
Johanna M.H. Levelt Sengers

Stratton Award—
Group:
Theodore E. Madey, John T. Yates, Jr.

Rosa Award—Alexander F. Robertson

Condon Award—Roy G. Saltman

Applied Research Award—Melvin Linzer

1979
Flemming Award—J. William Gadzuk

Gold Medal Awards—
Martin G. Broadhurst
Randall S. Caswell
Richard D. Deslattes
George G. Harman, Jr.
Morris Krauss
Philip D. LaFleur
William L. McLaughlin
Group:
James F. Schooley, Robert J. Soulen, Jr.

Stratton Award—James E. Zimmerman

Rosa Award—Louis Costrell

Condon Award—
Group:
Kenneth M. Evenson, David J. Wineland, Helmut Hellwig, John L. Hall.

Applied Research Award—Marshall D. Abrams

1980
Gold Medal Awards—
Dennis K. Branstad
Frederick E. Brinckman, Jr.
Lucy M. Cavallo
Ared Cezairliyan
William C. Cullen
Jon T. Hougen
Tamami Kusuda
Arthur G. Maki, Jr.
Robert E. Michaelis
Group:
Robert E. Edsinger, Leslie A. Guildner

Stratton Award—Evans V. Hayward

Rosa Award—W. Murray Bullis

Condon Award—
Group:
Robert J. Celotta, Daniel T. Pierce.

Applied Research Award—
Group:
John A. Simpson, Robert J. Hocken, William C. Haight.

1981
Gold Medal Awards—
Burton H. Colvin
Robert D. Cutkosky
J. William Gadzuk
Ernest E. Hughes
Harry H. Ku
Theodore E. Madey
William C. Martin
John T. Yates, Jr.

Stratton Award—
Group:
David M. Kerns, Allen C. Newell

Rosa Award—James A. Grundl

Condon Award—Donald G. McDonald

Applied Research Award—
Group:
C. McKay Allred, Glenn F. Engen, Cletus A. Hoer, Manly P. Weidman

Measurement Services Awards—
Woodward G. Eicke, Jr.
Robert R. Jones

1982
Flemming Award—Jon C. Geist

Gold Medal Awards—
John W. Cahn
Judah Levine
Sheldon M. Wiederhorn
Richard N. Wright
Group:
Richard D. Marshall, Edward O. Pfrang

Stratton Award—Jerome Kruger

Rosa Award—Elmer H. Eisenhower

Condon Award—Theodore E. Madey

Applied Research Award—Donald G. Eitzen

Measurement Services Award—
Group:
Robert W. Peterson, Linwood Jenkins.

1983

Gold Medal Awards—
Robert P. Blanc
David Garvin
Clark A. Hamilton
Raymond G. Kammer
Raymond D. Mountain
Richard P. Reed
Group:
James L. Blue, Charles L. Wilson.
Group:
J. Michael Rowe, John J. Rush.

Stratton Award—Martin G. Broadhurst

Rosa Award—Robert L. Scace

Condon Award—Isaac C. Sanchez

Applied Research Award—
Group:
David W. Allan, Alvin J.D. Clements, Dicky D. Davis, Marc A. Weiss.

Measurement Services Awards—
Gerald J. Harris
Jacquelyn A. Wise

1984

Gold Medal Awards—
Michael Danos
James J. Filliben
Peter L.M. Heydemann
Stephen R. Leone

Stratton Award—Morris Krauss

Rosa Awards—
John F. Heafner
Bradford M. Smith

Condon Award—Brian R. Lawn

Applied Research Award—Karla L. Hoffman

Astin Award—
Group:
Karl G. Kessler, John A. Simpson

1985
Gold Medal Awards—
Pierre J. Ausloos
Howard J.M. Hanley
Sharon G. Lias
John C. Stephenson
Group:
    Howard R. Baum, Ronald G. Rehm
Group:
    James C. Bergquist, John J. Bollinger, Wayne M. Itano, David J. Wineland.

Stratton Award—
Group:
    Richard L. Kautz, Donald B. Sullivan.

Rosa Award—Robert Schaffer

Condon Award—David J. Wineland

Applied Research Award—William L. McLaughlin

Astin Award—Albert D. Tholen

1986
Flemming Awards—
    Stephen R. Leone
    Harry S. Hertz

Gold Medal Awards—
James S. Albus
Andrι Deprit
Charles C. Han
Robert J. Hocken
Dale E. Newbury
Cedric J. Powell
Robert S. Roth
Mabel V. Vickers

Stratton Award—John W. Cahn

Rosa Award—George A. Uriano

Condon Award—John W. Lyons

Applied Research Award—
Group:
    Ronald F. Fleming, Robert G. Downing.

Astin Award—Norman B. Belecki

1987

Flemming Awards—
    Willie E. May
    Dale E. Newbury

Gold Medal Awards—
David A. Didion
Steve R. Domen
Michael R. Moldover
Raymond T. Moore
Philip N. Nanzetta
James J. Rhyne
Jack E. Snell
Francis E. Sullivan
Robb M. Thomson
Wing Tsang
Group:
    Robert J. Celotta, Daniel T. Pierce.

Stratton Award—William D. Phillips

Rosa Award—Daniel Gross

Condon Award—Kermit C. Smyth

Applied Research Award—David A. Didion

Astin Award—Roger E. Beehler

1988

Flemming Award—William D. Phillips

Gold Medal Awards—
Robert J. Carpenter
Douglas L. Franzen
Arnold H. Kahn
Curt W. Reimann
Stephen E. Stein

Stratton Award—Michael R. Moldover

Rosa Award—Samuel J. Schneider, Jr.

Condon Award—
Group
    David A. Didion, Mark O. McLinden.

Applied Research Award—Douglas L. Franzen

Astin Award—William C. Daywitt

1989

Gold Medal Awards—
George Birnbaum
Lloyd A. Currie
Harold E. Nelson
Joseph Reader
Emil Simiu
Group:
D. Wayne Hanson, David A. Howe, James L. Jesperson.
Group:
James A. Beall, Clark A. Hamilton, Richard E. Harris, Richard L. Kautz, Frances L. Lloyd.
Group:
Marvin E. Cage, Ronald F. Dziuba, P. Thomas Olsen, John Q. Shields, Barry N. Taylor, Edwin R. Williams.

Stratton Award—
Group
James C. Bergquist, John J. Bollinger, Wayne M. Itano, David J. Wineland.

Condon Award—Gregory B. McKenna

Rosa Award—Leonard Mordfin

Applied Research Award—James S. Albus

Astin Award—Mary C. Croarkin

1990

Flemming Award—Geoffrey B. McFadden

Gold Medal Awards—
Richard R. Cavanagh
James E. Faller
Katherine B. Gebbie
Oskars Petersons
Walter J. Stevens

Stratton Award—Charles C. Han

Rosa Award—Frank F. Oettinger

Condon Award—George G. Harman, Jr.

Applied Research Award—Howard M. Kingston

Astin Award—Group; Robert J. Carpenter, Alan Mink, George G. Nacht, John W. Roberts.

1991
Flemming Award—David J. Nesbitt

Gold Medal Awards—
David S. King
Billy W. Mangum
Geoffrey B. McFadden
Edward Prince
Tawfik M. Raby

Stratton Award—
Group:
Michael P. Casassa, Richard R. Cavanagh, Edwin J. Heilweil, David S. King, John C. Stephenson.

Rosa Award—Randall S. Caswell

Condon Award—Dale E. Newbury

Applied Research Award—Takashi Kashiwagi

Astin Award—Ronald F. Dziuba

1992
Flemming Award—Eric B. Steel

Gold Medal Awards—
Willie E. May
George A. Uriano
Wen-Li Wu

Stratton Award—Stephen R. Leone

Rosa Award—Vytenis Babrauskas

Applied Research Award—
Group:
Mark O. McLinden, Graham Morrison.

Astin Award—William C. Martin

Slichter Award—
Group:
Robert J. Celotta, Daniel T. Pierce.

1993
Gold Medal Awards—
William D. Phillips
Group:
Robert E. Drullinger, David J. Glaze, John P. Lowe.
Group:
High-Temperature Superconducting Electronics Team.

Stratton Award—
Group:
J. Michael Rowe, John J. Rush.

Condon Award—Charles R. Tilford

Rosa Award—
Group:
Dennis J. Reeder, Kristy L. Richie.

Applied Research Award—
Group:
Laurie Locasio-Brown, Steven J. Choquette.

Astin Award—
Group:
W. Tyler Estler, Yun Hsia Queen.

Slichter Award—
Group:
Stephen A. Osella, Theodore V. Vorburger, Pedro I. Espina, George E. Mattingly, Francis S. Biancaniello, Paul A. Boyer, Robert L. Parke, Stephen D. Ridder, H. Thomas Yolken.

Sources:
1968-1973 NBS Standard.
1974-1993 NBS/NIST Award Brochure Collection.

APPENDIX H

MEMBERS OF THE VISITING COMMITTEE FOR NBS AND THE VISITING COMMITTEE ON ADVANCED TECHNOLOGY FOR NIST

Public Law 56-177, which established the National Bureau of Standards as an agency of the Department of the Treasury on March 3, 1901, directed the creation of a Visiting Committee of five members, "men prominent in the various interests involved", to be appointed by the Secretary of the Treasury, to visit NBS at least annually, and to report to the secretary upon the efficiency of its scientific work and the condition of its equipment. Despite the transfer of NBS to the Department of Commerce and Labor in 1903 and the creation in 1913 of a separate Department of Commerce, the procedures of the Visiting Committee remained unchanged until 1988.

The text of Public Law 100-418, August 23, 1988, replaced the earlier Visiting Committee by a Visiting Committee on Advanced Technology (VCAT). The new committee, to be appointed by the NIST Director, was to be composed of nine members, at least five of whom were to be from U.S. industry. The VCAT was to meet at least quarterly and to provide an annual report on NIST, to be submitted to Congress through the Secretary of Commerce.

Visiting Committee, National Bureau of Standards

Albert Ladd Colby 1901-1907
Consulting engineer in metallurgy, South Bethlehem, Pennsylvania, and secretary, Association of American Steel Manufacturers.

Elihu Thomson 1901-1918
Electrical engineer, General Electric Company, Lynn, Massachusetts.

Ira Remsen 1901-1909
Director of Chemical Laboratory and President, John Hopkins University.

Henry S. Pritchett 1901-1910
President, Massachusetts Institute of Technology; later, President, Carnegie Foundation for the Advancement of Teaching.

Edward L. Nichols 1901-1911
Professor of physics, Cornell University.

Robert S. Woodward 1908-1912
President, Carnegie Institution of Washington.

Henry M. Howe 1909-1914
Professor of metallurgy, Columbia University.

Arthur G. Webster 1910-1915
Director, Physics Laboratory, Clark University.

John F. Hayford 1912-1921
Director, College of Engineering, Northwestern University.

Arthur E. Kennelly 1912-1917
Professor of electrical engineering, Harvard University.

John R. Freeman 1915-1924; 1926-1931
Consulting engineer, Providence, Rhode Island.

William A. Noyes 1915-1920
Director, Chemical Laboratory, University of Illinois.

Joseph S. Ames 1917-1922
Director, Physical Laboratory, Johns Hopkins University.

Wilder D. Bancroft 1920-1925
Professor of physical chemistry, Cornell University.

Fred W. McNair 1921-1923
President, Michigan College of Mines (1921-23).

Ambrose Swasey 1921-1926
Chairman of the Board, Warner & Swasey Company, Cleveland, Ohio.

Samuel W. Stratton 1923-1931
President, Massachusetts Institute of Technology.

Gano Dunn 1923-1948
President, J.G. White Engineering Corporation, New York.

William F. Durand 1924-1929
Professor of mechanical engineering, Leland Stanford University.

Willis R. Whitney 1925-1930
Director, General Electric Research Laboratory, Schenectady, New York.

Charles F. Kettering 1929-1934; 1947-1952
Director of Research and Vice President, General Motors Corporation.

Charles L. Reese 1930-1935
Consulting chemist to E.I. du Pont de Nemours & Company.

Morris E. Leeds 1931-1941
President, Leeds & Northrup Co., Philadelphia, Pennsylvania.

Karl T. Compton 1931-1947
President, Massachusetts Institute of Technology.

William D. Coolidge 1935-1949
Vice President and Director of Research, General Electric Company.

Frank B. Jewett 1935-1945
Vice President for Research & Development, American Telephone & Telegraph Co.; President, National Academy of Sciences.

Vannevar Bush 1942-1946
President, Carnegie Institution of Washington; Director, Office of Scientific Research and Development.

Harold C. Urey 1945-1950
Research Professor of chemistry, University of Chicago.

Eugene P. Wigner 1946-1951
Metallurgical Laboratory, University of Chicago; Director of Research, Clinton Laboratories, Oak Ridge, Tennessee.

Robert F. Mehl 1948-1953
Director, Metals Research Laboratory, Carnegie Institute of Technology.

Donald H. Menzel 1949-1954
Chairman, Department of astronomy, Harvard University; Associate Director, Harvard Observatory.

Detlev W. Bronk 1950-1960
President, Johns Hopkins University.

John H. Van Vleck 1951-1956
Dean, Division of Applied Science, Harvard University.

Mervin J. Kelly 1952-1962
President, Bell Telephone Laboratories.

Clyde E. Williams 1953-1958
Director, Battelle Memorial Institute, Columbus, Ohio.

Crawford H. Greenewalt 1954-1964
President, E.I. du Pont de Nemours & Company.

Frederick Seitz 1956-1961
Chairman, Department of Physics, University of Illinois.

Lloyd V. Berkner 1958-1965
President, Associated Universities, New York; President, Southwest Graduate Research Center.

Charles H. Townes 1960-1965
Professor, Department of physics, Columbia University; consultant, Brookhaven National Laboratories.

Emanuel R. Piore 1962-1972
Vice President and Chief Scientist, International Business Machines Corporation.

Elmer W. Engstrom 1963-1971
President, Radio Corporation of America.

Paul C. Cross 1964-1969
President, Mellon Institute.

Norman F. Ramsey 1965-70; 1982-1987
Professor, Department of physics, Harvard University.

Robert L. Sproull 1966-1971
Vice President, University of Rochester.

Jack E. Goldman 1969-1974
Senior Vice President for Research and Development, Xerox Corporation.

James C. Fletcher 1970-1971
President, University of Utah.

H. Guyford Stever 1971-1976
President, Carnegie Mellon University.

Milton Harris 1971-1973
President, Harris Research Laboratories, Incorporated.

Arthur M. Bueche 1971-1975
Vice-President for Research and Development, General Electric Company.

John G. Truxall 1972-1976
Dean, College of Engineering, State University of New York at Stony Brook.

Charles E. Peck 1973-1977
Vice-President, Construction Group, Owens-Corning Fiberglas Corporation.

Edwin A. Gee 1973-1978
Senior Vice President, E.I. du Pont de Nemours & Company; International Paper Corporation.

Robert H. Dicke 1974-1979
Professor of physics, Princeton University.

W. Dale Compton 1975-1981
Vice-President for Research, Ford Motor Company.

William D. Carey 1976-1981
Executive Officer, American Association for the Advancement of Science.

William K. Linvill 1978-1982
Department of engineering economics, Stanford University.

Dorothy M. Simon 1978-1983
Vice-President for Research, AVCO Corporation.

Walter H. Stockmayer 1979-1984
Department of chemistry, Dartmouth College.

G. King Walters 1980-1982; 1992-1994
Dean, Physics Department, Rice University.

Russell G. Meyerand, Jr. 1980-1985
Vice-President for Technology, United Technologies Corporation.

Bernard M. Oliver 1982-1986
Vice-President, Hewlett Packard Company.

Robert H. Pry 1983-1987
Center for Innovative Technology; Consultant, Gould Incorporated.

William D. Manly 1984-1989
Senior Vice-President, Cabot Corporation; Consultant, Oak Ridge National Laboratory.

Arden L. Bement 1985-1991
Vice-President, Technical Resources, Science & Technology Department, TRW Incorporated.

The Visiting Committee on Advanced Technology, National Institute of Standards and Technology

William D. Manly 1988-1989
Senior Vice-President, Cabot Corporation; Consultant, Oak Ridge National Laboratory.

Arden L. Bement 1988-1991
Vice-President, Technical Resources, Science & Technology Department, TRW Incorporated.

John G. Bollinger 1988-1991
Dean, College of Engineering, University of Wisconsin.

John P. McTague 1988-1990
Vice-President for Research, Ford Motor Company.

Nolen M. Ellison 1988-1989
President, Cuyahoga Community College.

Jeanette G. Grasselli 1988-1991
Director of Research Enhancement, Ohio University.

William J. Spencer 1988-1989
Vice-President for Corporate Research, Xerox Corporation.

William P. Slichter 1988-1990
Executive Director, Materials Science and Engineering Division, AT&T Bell Laboratories.

William G. Howard Jr. 1988-1993
Senior Fellow, National Academy of Engineering.

Edward C. Heffron 1990-1993
Director, Food Division, Michigan Department of Agriculture.

Albert R.C. Westwood 1990-1995
Vice-President for Research and Technology, Martin Marietta Corporation.

Richard S. Nicholson 1990-1992
Executive Officer, American Association for the Advancement of Science.

Nam P. Suh 1990-1993
Professor of manufacturing and of mechanical engineering, Massachusetts Institute of Technology.

Robert W. Lucky 1991-1994
Vice-President for Applied Research, Bellcore Corporation.

Robert J. Hermann Senior Vice President for Science and Technology, United Technologies Corporation.	1992-1998
Edward M. Chait Vice-President for Business Development, Intergen Company.	1992-1994
Maxine L. Savitz General Manager for Ceramic Components, Allied Signal, Incorporated.	1993-1999
Fred W. Kittler Jr. Vice President, J. P. Morgan Investment Management Company.	1994-2000
Robert J. Saldich President, Raychem Corporation.	1994-2000
George M. Whitesides Professor of chemistry, Harvard University.	1994-1997
Craig I. Fields Vice Chairman, Alliance Gaming Corporation.	1995-2001
James C. McGroddy Senior Vice President, IBM Corporation.	1995-2001
Howard D. Samuel Senior Fellow, Council on Competitiveness.	1995-2000
David L. Tennenhouse Principal Research Scientist, MIT Laboratory for Computer Science.	1996-1997
Duane A. Adams Vice Provost for Research, Carnegie Mellon University.	1996-1999
Dwight D. Carlson Vice Chairman, Perceptron, Incoporated.	1996-1999
Victoria F. Haynes Vice President for Research & Development, The B.F. Goodrich Company.	1996-1999
Lynn R. Williams President (Retired), United Steel Workers of America.	1996-2000
Milton M. Chang Chairman, New Focus, Incorporated.	1996-

(Dates indicate term(s) of appointments.)

Source:

Carolyn J. Stull, NIST Visiting Committee Office.

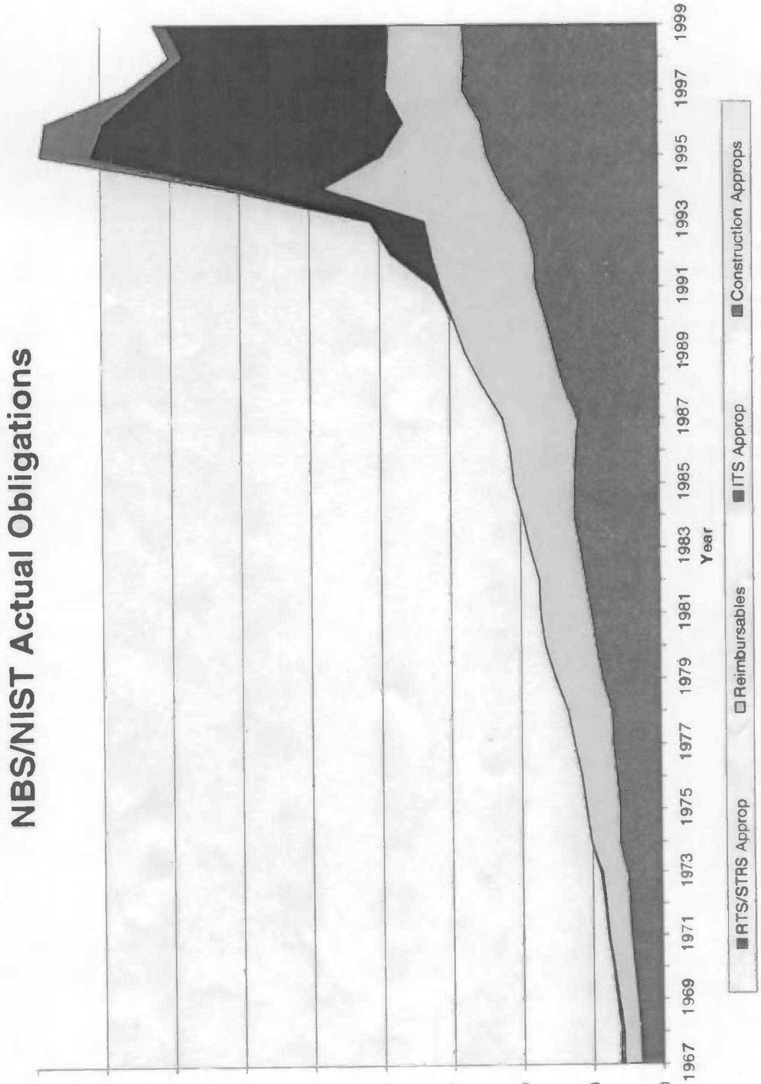
APPENDIX I

NBS/NIST ACTUAL OBLIGATIONS, 1967-1999

On the following page is presented, in graphical form, a representation of monies spent by NBS/NIST during the period 1967-1999. Four categories of expenditure are indicated:

- Congressionally appropriated funds earmarked for NBS/NIST Research and Technical Services (RTS) or Scientific and Technical Research and Services (SRTS). During the stated period, these funds—used primarily to support scientists engaged in traditional NBS work—grew from $30 M per year to $280 M per year.
- Funds obtained principally from other government agencies for research services rendered, from the sale of Standard Reference Materials, and from calibration services (Reimbursables). Funds received from these sources grew from $25 M per year to just over $70 M per year during 1967-1999.
- Congressionally appropriated funds earmarked for support of the Advanced Technology Program and the Manufacturing Extension Partnership (ITS Approp). Existing only after the change of NBS to NIST, these funds reached peak levels above $400 M per year during 1995 and 1996.
- Congressionally appropriated funds earmarked for new construction and major renovations of NIST facilities (Construction Approps). These funds reached peak levels above $70 M during 1995 and 1996.

Source: Janet B. Miller, Chief, Formulation and Financial Management Section, NIST Budget Division.


NBS/NIST Actual Obligations
$M
900
800
700
600
500
400
300
200
100
0
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year
RTS/STRS Approp
Reimbursables
ITS Approp
Construction Approps

APPENDIX J

NBS/NIST PUBLICATIONS

This appendix contains a listing of both periodical and non-periodical publications from NBS/NIST. Many of the publications enjoyed only a limited life, then were superseded or stopped.

Besides the publications listed here, NBS/NIST scientists and engineers wrote numerous books and book chapters, edited many technical conference proceedings, and published many archival technical papers in non-NBS/NIST journals. References to these publications can be found in NBS Circular 460 and its supplement (for the years 1901-1957); in NBS Miscellaneous Publication 240 and its supplement (1957-1966); and NBS/NIST Special Publication 305 and its many supplements (1966--present).

In 1991, total NIST Publications numbered over 1,700 separate items.

Following each entry is its NIST Office of Information Services call number.

Aeronautic Instruments Circulars
TL589.U47
No. 1-51 (1918-1921)

These technical circulars discussed the principles involved in the various aeronautic instruments and the methods of testing employed by the Aeronautic Instruments Section. The confidential reports were duplicated for temporary use and served to make the results immediately available for the instruction of the experts engaged in aviation work in the technical divisions of the Army and Navy. They were not for publication.

Aeronautic Power Plants Reports
TL521.A33
No. 3-53 (1918-1919)

These technical reports were results of investigations by the NBS Airplane Power Plant Section for the National Advisory Committee for Aeronautics. The reports were confidential for use by the Army, Navy, and authorized civilians.

Annual Reports
QC100.U55
Fiscal Year 1902–Fiscal Year 1985

The title varies and includes:

Annual Report of the Director of the National Bureau of Standards for the Fiscal Year Ended . . . (June 30, 1902—June 30, 1903)

Annual Report of the Director of the Bureau of Standards to the Secretary of Commerce and Labor for the Fiscal Year Ended . . . (June 30, 1904—June 30, 1912)

Annual Report of the Director, Bureau of Standards to the Secretary of Commerce for the Fiscal Year Ended . . . (June 30, 1913–June 30, 1921)

Annual Report of the Director of the Bureau of Standards to the Secretary of Commerce for the Fiscal Year Ended . . . (June 30, 1922 –June 30, 1932)

Reprinted from the Annual Report of the Secretary of Commerce. Bureau of Standards. (1933)

Reprinted from the Annual Report of the Secretary of Commerce. National Bureau of Standards. (1934-1942)

The *Annual Reports of the National Bureau of Standards* for the fiscal years 1943, 1944, and 1945 were not published because of economy measures taken during World War II. The manuscripts for these annual reports were submitted to the secretary of commerce in typewritten form.

Annual Report of the National Bureau of Standards. Reprinted from the Annual Report of the Secretary of Commerce. (1946-1948)

Annual Report . . . National Bureau of Standards. (1949-1952)

Biennial Report 1953 and 1954, National Bureau of Standards. From the Preface: At the scheduled time for the preparation and release of the 1953 report the Bureau was undergoing comprehensive survey by an Ad Hoc Committee [Kelly Committee] appointed by the secretary of commerce to "evaluate the present functions and operation of the NBS in relation to present national needs." A number of important changes affecting the over-all Bureau program were made as a result of this survey. It was considered more appropriate to delay the report for a year in order to include the complete recommendations of the Ad Hoc Committee rather than to report on them partially.

Annual Report . . . National Bureau of Standards. (1955-1957)

Research Highlights of the National Bureau of Standards. Annual Report, Fiscal Year . . . (1958-1963)

Technical Highlights of the National Bureau of Standards. Annual Report, Fiscal Year . . . (1964-1970)

NBS 1971 Annual Report. Special Publication (SP) 397 June 1972

National Bureau of Standards, NBS. (1972) SP-367 Oct 1972

National Bureau of Standards, NBS. [1973] SP-397 June 1974

NBS Annual Report Fiscal Year 1974. SP-418 March 1975

National Bureau of Standards Annual Report FY 1975. SP-437 Dec 1975

National Bureau of Standards, Perspectives on Standards. (1976) SP-467 March 1977

Science on it's Way to Work, Activities of the National Bureau of Standards. [1977] SP-498 April 1978

National Bureau of Standards, A National Resource for Science and Technology, Fiscal Year 1978. SP-538 July 1979

1979 was not published.

National Bureau of Standards 1980. SP-600 Jan 1981

National Bureau of Standards 1982. [covered fiscal years 1981 and 1982] SP-643 Feb 1983

National Bureau of Standards. [1983] SP-679 July 1984

National Bureau of Standards. [1985] SP-679 July 1984, revised April 1986.

The last annual report in this series was published in 1986 as a revision of the previous report. The two publications differ in all but a few minor areas.

Descriptions of the technical activities of the major organizational units of NBS/NIST—but without overall personnel or financial information—were published in a series of Special Publication documents during the period 1984 to the present. Prominent among these were the following series:

NIST Research Reports 1984-1987;

NIST Research Reports 1988-1991; and

Guide to NIST 1993- present.

Applied Mathematics Series

QA3.U5

No. 1-63 (1948-1973)

This series contains mathematical tables, manuals and studies of special interest to physicists, engineers, chemists, biologists, mathematicians and others engaged in scientific and technical work. Some of the publications are reissues of the Mathematical Tables prepared by members of the Project for the Computation of Mathematical Tables. This series is inactive as none have been published since 1973.

Basic Radio Propagation Predictions Series

This monthly series was prepared by the Interservice Radio Propagation Laboratory (IRPL) which was set up during WWII by the United States Joint Communications Board at NBS. The series succeeded "Radio Propagation Conditions," also prepared by the IRPL. The predictions series was initially restricted and available only to the military as a basic supplement to the IRPL's "Radio Propagation Handbook" issued by the military. Predictions were made three months in advance. May 1, 1946, the wartime IRPL ceased to exist and its duties and functions were assumed by the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards. In July 1946 the series was made available by annual subscription to those concerned with radio communication in determining the best sky-wave frequencies over any path at any time of day for average conditions. In September 1947, various maps, charts, diagrams, and nomograms needed to make practical application of the world-contour charts were added with examples of their use.

Basic Radio Propagation Predictions, IRPL Series D
TK6570.B7U47
No. 1-22 (1944-June 1946)
Continued by: Basic Radio Propagation Predictions, CRPL Series D

Basic Radio Propagation Predictions, CRPL Series D
TK6570.B7U47
No. 23-220 (July 1946-1962)
Continues: Basic Radio Propagation Predictions, IRPL Series D
Superseded by: Ionospheric Predictions

Building and Housing
TH1.U4
No. 1-18 (1923-1932)

This series contained reports of the work of the Building and Housing Division that included gathering and distributing scientific, practical, statistical, and other information tending to reduce costs, and encourage and improve construction and housing. It covered investigations for use in framing local building and plumbing codes, and a study of problems connected with city zoning. Information on the prices, production, consumption, and stocks of building materials, and on building activity was collected, analyzed, and distributed. Special attention was paid to factors bearing on the housing problem. The work included studies of building practices, and cooperative efforts to reduce seasonal operations and otherwise eliminate waste in the construction industries.

Building Materials and Structures Reports
TA410.U48
No. 1-152 (1938-1959)

This series reported the results of Bureau investigations on the properties and suitability of new materials and new methods of construction. The program was carried out with the cooperation and advice of the housing agencies of the Government. The objective was to furnish the Government, the building industry, and the public with technical information that would be useful with particular reference to low-cost housing. This series was discontinued in July 1959 and papers on building technology were then published in the *Journal of Research*—usually *Section C. Engineering and Instrumentation*—or the Monograph series.

Building Science Series *see* NIST Building Science Series

Bulletin of the Bureau of Standards *see* Journal of Research

Circulars *see* National Bureau of Standards Circular

Commercial Standards
QC100.U5553
Nos. 0-274 (1928-1966)

Commercial standards were voluntary, recorded standards agreed upon by producers, distributors, and consumers, covering terminology, types, classifications, grades, sizes, and use characteristics of manufactured products as a basis for better understanding between buyers and sellers. They generally included standard methods of test, rating, certification, and labeling, and provided a uniform basis for fair competition. Each standard included a list of members of the standing committee, a history of the project, and list of acceptors. After 1966 as *Commercial Standards* were revised, they became *Product Standards* and in 1969, *Voluntary Product Standards.*

Commercial Standards Monthly
HD62.U3
Vol. [1]-9 (1925-1933)

This periodical was a review of progress in commercial simplification and standardization. It covered the national movement initiated by President Hoover for the reduction of needless sizes and varieties of products and the promotion of voluntary commercial standardization by industry.

Consumer Information Series
TX335.A1U6
No. 1-10 (1970-1978)

This series contained practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace. This series is inactive as none have been published since 1978.

CRPL Report
QC503.U5
No. 1-1– 9-10 (July 1946-1950)
Supersedes: IRPL Report

Reports prepared by the Central Radio Propagation Laboratory at NBS.

CRPL-F, PART A: IONOSPHERIC DATA

These bulletins represent a variety of data collected by IRPL, later CRPL, in the course of its research and service activities. The data were made available for use in research on radio propagation and the ionosphere, and in other geophysical applications.

Ionospheric Data, IRPL-F
QC503.U5
No. 1-22 (1944– June 1946)
Continued by: Ionospheric Data, CRPL-F

Ionospheric Data, CRPL-F
QC503.U5
No. 23-134 (July 1946-1955)
Continues: Ionospheric Data, IRPL-F
Split into two parts: CRPL-F, Part A and CRPL-F, Part B

CRPL-F, Part A: Ionospheric Data
QC503.U5
No. 135-256 (1955-1965)
Continues in part: Ionospheric Data, CRPL-F
Continued as U.S. Environmental Science Services Administration. Institute for Telecommunication Sciences. CRPL-FA: Ionospheric Data

CRPL-F, Part B: Solar-Geophysical Data
QC503.U51
No. 135-256 (1955-1965)
Continues in part: Ionospheric Data, CRPL-F
Continued as U.S. Environmental Science Services Administration. Institute for Telecommunication Sciences. CRPL-FB: Solar-Geophysical Data

DIMENSIONS

During World War I the Bureau originally issued the *Confidential Bulletin* as an information bulletin for the military of ordnance work done by the Bureau. The name was changed to *Technical News Bulletin* (TNB) and the first issue, no. 26, June 20, 1919, was also issued as *Confidential Bulletin* no. 26, June 20, 1919. These two publications were the same except for information items concerning ordnance that were blanked out of the TNB.

The *Technical News Bulletin,* available by annual subscription, summarized the current research, development, and test activities of the Bureau. The articles were brief, with emphasis on the results of research and their significance, chosen for their importance to other scientists, engineers, and to industry. Resumes of longer research reports, important national and international conferences on fundamental science in which the Bureau represented the Nation, and a bibliography of all publications by members of the staff as published were included. The Bulletin was designed to give a succinct account of the current work of the Bureau.

Dimensions continued the TNB in a popular magazine format to inform scientists, engineers, businessmen, industry, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on the work at NBS. It highlighted and reviewed such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance in addition to Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing.

Confidential Bulletin
T1.U45
No. 1-26 (Dec. 15, 1917–June 20, 1919)
Continued by: Technical News Bulletin of the Bureau of Standards

Technical News Bulletin of the Bureau of Standards
T1.U45
No. 26-204 (1919-1934)
Continued by: Technical News Bulletin of the National Bureau of Standards

Technical News Bulletin of the National Bureau of Standards
T1.U45
No. 205– Vol. 57 no. 7 (May 1934–July 1973)
(after no. 356, Dec. 1946, changed to volume numbering with Vol. 31 no. 1, Jan. 1947)
Continues: Technical News Bulletin of the Bureau of Standards
Continued by: Dimensions: the Magazine of the National Bureau of Standards

Dimensions: the Magazine of the National Bureau of Standards
T1.U45
Vol. 57 no. 8–Vol. 65 no. 8 (Aug. 1973–Oct. 1981)
Continues: Technical News Bulletin of the National Bureau of Standards
Additional title: Dimensions/NBS

Federal Information Processing Standards Publications
JK468.A8A3
No. 0 (1968)–present

This series is the official publication relating to standards and guidelines developed for Federal computer systems by the National Institute of Standards and Technology and promulgated under the Federal Property and Administrative Services Act of 1949, Section 111(d), as amended by the Computer Security Act of 1987, Public Law 100-235 (101 Stat. 1724) January 8, 1988.

Federal Specifications

The Bureau developed specifications for the purchase of supplies (other than foods and drugs) for the Federal Government. These specifications were generally recognized as dependable guides by many large organizations and purchasing agencies in achieving purchasing economy. The Bureau endorsed these specifications and published them for distribution. The first one published by the Bureau was Circular 13, *Standard Specifications for the Purchase of Carbon-Filament Incandescent Lamps,* in 1907. The first official U.S. Government specification, authorized by Presidential order, was published as Bureau Circular C33, *United States Government Specification for Portland Cement,* in 1912. Specifications were published in the Circular and Miscellaneous Publications series.

In 1921 The Federal Specifications Board was created by the Bureau of the Budget to unify specifications already available to government agencies. Bureau specifications accepted by the Board became official standards and were binding on all departments of the Federal Government.

Gage Section Communications
TJ1166.U5
1919-1920

The various communications of the Gage Section of the Weights and Measures Division contained information about the practical problems of gauges and gauging methods including work carried out with the National Screw Thread Commission.

Handbooks *see* NIST Handbooks

Hydraulic Laboratory. Bulletin. Series B: Hydraulic Laboratories in the United States
TC1.U5
(1933 and 1935, 1st rev.)

This series updated *Hydraulic Laboratories in the United States of America,* giving descriptions of 47 hydraulic laboratories in the United States.

Hydraulic Research in The United States

These reports represented a cooperative attempt on the part of the hydraulic laboratories in the United States to bring about the effective interchange of information relating to research projects being carried out in these laboratories. NBS served as a central agency to compile, publish and distribute information related to current hydraulic laboratory research.

Hydraulic Laboratory. Bulletin. Series A: Current Hydraulic Laboratory Research in the United States
TC1.U51
No. 1-10 (1933-1942)
Continued by: *Hydraulic Research in the United States*

Hydraulic Research in the United States
TC1.U51
Vol. 11-14 (1947-1950)
Continues: Hydraulic Laboratory. Bulletin. Series A: Current Hydraulic Laboratory Research in the United States

In 1951 *Hydraulic Research in the United States* became part of the Miscellaneous Publications series, and an annual issue was published, keeping the title *Hydraulic Research in the United States.* In 1969 the series name changed to Special Publications and the frequency of publication of *Hydraulic Research* became biennial. In 1972 the title changed to *Hydraulic Research in the United States and Canada.* Publication of this title ended in 1978.

Miscellaneous Publications 201, 205, 208, 210, 215, 218, 221, 224, 227, 231, 238, 245, 249, 261, 270, 280
Special Publications 316, 346, 382, 443, 497, 583

International Aircraft Standards
TL671.1.U5
(1917-1918)

International Aircraft Standards, adopted by the International Aircraft Standards Board, were specifications that resulted from testing done at NBS. The classification of specifications covered general inspection and testing instructions, raw materials, fabricated material, and fabricated parts.

Ionospheric Predictions
TK6570.B7U47
No. 1-36 (1963-1965)
Supersedes: Basic Radio Propagation Predictions, CRPL Series D

The CRPL *Ionospheric Predictions* were issued monthly as an aid in determining the best sky-wave frequencies over any transmission path, at any time of day, for average conditions for the month. Issued three months in advance, each issue provided tables of numerical coefficients that defined the functions describing the predicted worldwide distribution of foF2 and M(3000)F2 and maps for each even hour of Universal Time of MUF(Aero)F2 and MUF(4000)F2.

IRPL Report
TK6540.U5
No. 1-35 (1943-June 1946)
Superseded by: CRPL Report

Reports prepared by the Interservice Radio Propagation Laboratory at NBS.

Journal of Physical and Chemical Reference Data
Q199.J65
Vol. 1 (1972)– present

This journal provides critically evaluated physical and chemical property data and critical reviews of measurement techniques. It is not an outlet for original experimental measurements or for review articles of a descriptive or primarily theoretical nature. The National Standard Reference Data System is one source of contributions to the Journal. JPCRD is published by the American Chemical Society and the American Institute of Physics for NIST.

JOURNAL OF RESEARCH

Results of research in science and technology were reported in the *Scientific Papers.* The first 14 volumes of the *Scientific Papers* were issued as the *Bulletin of the Bureau of Standards* and the separate papers were called "Reprints." Results of investigations of materials and methods of testing were reported in the *Technologic Papers.* In July 1928 the *Scientific Papers* and *Technologic Papers* were combined and issued under the title *Bureau of Standards Journal of Research.*

Complete scientific reports of the Bureau's research and development, both experimental and theoretical, in physics, chemistry, and engineering and the results of test and instrumentation activities in these fields were printed in the *Journal of Research.* The subject matter of the reports embraced all fields of work conducted at the Bureau. *Research Papers* were reprints of individual articles appearing in the monthly issues of the *Journal of Research.* They were made available in this form to serve the need of research workers, technical groups, and others for the separate papers relating to the particular subjects in which they cooperated or were interested. In July 1959 the Bureau began publishing the Journal in four separate sections, A, B, C, and D, and the *Research Papers* were discontinued. Issued six times a year.

Journal of Research of the National Bureau of Standards, Section A. Physics and Chemistry was of interest primarily to scientists working in these fields. It covered a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year.

Journal of Research of the National Bureau of Standards, Section B. Mathematics and Mathematical Physics presented studies and compilations designed mainly for the mathematician and the theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programing of computers and computer systems were covered, together with short numerical tables. In 1967 *Mathematics and Mathematical Physics* changed to *Mathematical Sciences.* Issued quarterly.

Journal of Research of the National Bureau of Standards, Section C. Engineering and Instrumentation reported research and development results of interest chiefly to the engineer and the applied scientist. It included many of the new developments in instrumentation resulting from the Bureau's work in physical measurement, data processing, and development of test methods. It also covered some of the work in acoustics, applied mechanics, building research, and cryogenic engineering. Issued quarterly. Ceased publication at end of 1972.

Journal of Research of the National Bureau of Standards, Section D. Radio Propagation reported research in radio propagation, communications, and upper atmospheric physics. Topics covered included propagation in ionized media, scattering by turbulence, effect of irregular terrain on propagation, diffraction and scattering by solid obstacles, propagation through time-varying media, surface waves, and antennas. In January 1964, *Radio Propagation* changed to *Radio Science.* Issued six times a year.

Journal of Research of the National Bureau of Standards, Section D. Radio Science was published monthly by the National Bureau of Standards in cooperation with the U.S. National Committee of the International Scientific Radio Union (URSI). It served as the principal publication outlet for the research of the NBS Central Radio Propagation Laboratory and the scientific activities of the USNC of URSI; it also carried selected papers from the NBS Radio Standards Laboratory. *Radio Science* presented research papers, as well as occasional survey articles, in radio propagation, communications, and radio science generally. Beginning with the January 1966 issue, *Radio Science* was published by the Environmental Science Services Administration (ESSA) after the transfer of the Central Radio Propagation Laboratory from NBS to ESSA. The scope and coverage remained the same. It continued to be cosponsored by the U.S. National Committee of the International Scientific Radio Union. The title of the journal was changed to simply *Radio Science* with new volume numbering.

In July 1977 Sections A and B were combined under its former title *Journal of Research of the National Bureau of Standards* and issued six times a year.

As of August 23, 1988, the National Bureau of Standards (NBS) became the National Institute of Standards and Technology (NIST) when the Omnibus Trade and Competitiveness Act was signed into law. The title was changed to *Journal of Research of the National Institute of Standards and Technology* with the Volume 93, no. 6 (November-December 1988) issue to reflect the organizational name change.

Bulletin of the Bureau of Standards
QC1.U5
Vol. 1-14 (1904-1919)

Scientific Papers of the Bureau of Standards
QC1.U572
Vol. 15-22 (1919-1928)
Merged with: Technologic Papers of the Bureau of Standards, to form: Bureau of Standards Journal of Research

Technologic Papers of the Bureau of Standards
T1.U4
Vol. 1-22 (1910-1928)
Merged with: Scientific Papers of the Bureau of Standards, to form: Bureau of Standards Journal of Research

Bureau of Standards Journal of Research
QC1.U52
Vol. 1-12 (1928-1934)
Formed by the union of: Scientific Papers of the Bureau of Standards, and Technologic Papers of the Bureau of Standards
Continued by: Journal of Research of the National Bureau of Standards

Journal of Research of the National Bureau of Standards
QC1.U52
Vol. 13-62 (1934-1959)
Continues: Bureau of Standards Journal of Research
Split into four parts and continued by Sections A, B, C, and D

Journal of Research of the National Bureau of Standards. Section A: Physics and Chemistry
QC1.U522
Vol. 63A-81A (1959-1977)
Continues in part: Journal of Research of the National Bureau of Standards
Merged with: Journal of Research of the National Bureau of Standards. Section B, to form: Journal of Research of the National Bureau of Standards

Journal of Research of the National Bureau of Standards. Section B: Mathematics and Mathematical Physics
QA1.U57
Vol. 63B-71B (1959-1967)
Continues in part: Journal of Research of the National Bureau of Standards
Continued by: Journal of Research of the National Bureau of Standards. Section B: Mathematical Sciences

Journal of Research of the National Bureau of Standards. Section B: Mathematical Sciences
QA1.U57
Vol. 72B-81B (1968-1977)
Continues: Journal of Research of the National Bureau of Standards. Section B: Mathematics and Mathematical Physics
Merged with: Journal of Research of the National Bureau of Standards. Section A, to form: Journal of Research of the National Bureau of Standards

Journal of Research of the National Bureau of Standards. Section C: Engineering and Instrumentation
QC100.U5554
Vol. 63C-76C (1959-1972)
Continues in part: Journal of Research of the National Bureau of Standards
Ceased publication in 1972.

Journal of Research of the National Bureau of Standards. Section D: Radio Propagation
QC973.U46
Vol. 63D-67D (1959-1963)
Continues in part: Journal of Research of the National Bureau of Standards
Continued by: Journal of Research of the National Bureau of Standards. Section D: Radio Science

Journal of Research of the National Bureau of Standards. Section D: Radio Science
QC973.U46
Vol. 68D-69D (1964-1965)
Continues: Journal of Research of the National Bureau of Standards. Section D: Radio Propagation
Ceased publication by NBS in 1965.

Journal of Research of the National Bureau of Standards
QC1.U524
Vol. 82-93 no. 5 (1977-1988)
Formed by the union of its Sections A and B
Continued by: Journal of Research at the National Institute of Standards and Technology

Journal of Research of the National Institute of Standards and Technology
QC1.U524
Vol. 93 no. 6 (1988)–present
Continues: Journal of Research of the National Bureau of Standards

LETTER CIRCULARS

Letter Circulars 1-1040 are mimeographed, irregularly published lists of Bureau publications and references, and general information concerning specific subjects on which popular interest had been demonstrated by inquiries addressed to the Bureau. With no. 1041 (1966) the Letter Circulars changed from a report format to that of brochures, booklets, and charts. They are still an informal series and not subject to a review process.

Letter Circular of the Bureau of Standards
QC100.U5775
No. 1-411 (1921-1934)

Letter Circular of the National Bureau of Standards
QC100.U5775
No. 412–1040 (1934-1962)
No. 1041–1134 (1966-1984).

Letter Circular of the National Institute of Standards and Technology
QC100.U5775
No. 1135 (1988) – present.

Limitation of Variety Recommendations
No. 1 (September 1, 1924)

Apparently only one "Elimination of Waste–Limitation of Variety Recommendation" was published (listed in "Publications of the Bureau of Standards, 1901–June 30, 1925," 7th ed. final, pg. 215. Circular no. 24) No mention of this series is made in the "Supplementary List of Publications of the Bureau of Standards, (July 1, 1925, to December 31, 1931)" or any thereafter.

Mathematical Tables Series
QA47.U51
No. 1-37 (1939-1946)

The tables (with the exception of MT15) were prepared by the Mathematical Tables Project for the computation of mathematical tables. The project, conducted by the Federal Works Agency, Work Projects Administration (WPA) for the city of New York, was under the sponsorship of, and tables made available through, the National Bureau of Standards. Selected for tabulation were functions of fundamental importance in pure and applied mathematics in the most useful range and interval of the argument. They are of special interest to physicists, engineers, chemists, biologists, mathematicians and others engaged in scientific and technical work.

In 1943 the project was administratively transferred from the WPA to the Bureau, but it remained in New York. When the National Applied Mathematics Laboratories was established at NBS in July 1947, the Mathematical Tables Project moved from New York to Washington, DC and became a part of the NAML's Computation Laboratory.

MT-18, MT-30, and MT-37 were originally printed as part of the series in the "Bulletin of the American Mathematical Society".

MT-19—MT-29, and MT-31—MT-36 were originally printed as part of the series in the "Journal of Mathematics and Physics".

Miscellaneous Publications *see* NIST Special Publications

Monographs *see* Monographs

National Bureau of Standards Circulars

Circulars were compilations of information on various subjects related to the Bureau's scientific, technical, and engineering activities. They included not only the results of Bureau studies, but give data of general interest from other sources.

This series also contained *Recommended Specifications, United States Government Specifications,* and *United States Government Master Specifications* formerly issued by the Bureau. These bore a specification number in addition to the Bureau Circular number, but all of these specifications were canceled or superseded by *Federal Specifications,* now formulated by the Federal Specifications Board. The series was discontinued in June 1959 and "circular" material was directed to the *Journal of Research* and the Monograph series.

Circular of Information of the National Bureau of Standards
QC100.U554
No. 1-4 (1902-1903)
Continued by: Bureau Circular—Department of Commerce and Labor, Bureau of Standards

Bureau Circular—Department of Commerce and Labor, Bureau of Standards
QC100.U555
No. 1-20 (1903-1909)
Continues: Circular of Information of the National Bureau of Standards
Continued by: Circular of the Bureau of Standards

Circular of the Bureau of Standards
QC100.U555
No. 21-404 (1910-1934)
Continues: Bureau Circular—Department of Commerce and Labor, Bureau of Standards
Continued by: Circular of the National Bureau of Standards

Circular of the National Bureau of Standards
QC100.U555
No. 405-459 (1934-1948)
Continues: Circular of the Bureau of Standards
Continued by: National Bureau of Standards Circular

National Bureau of Standards Circular
QC100.U555
No. 460-603 (1947-1959)
Continues: Circular of the National Bureau of Standards
Superseded by: NBS Monograph

National Bureau of Standards Reports
Nos. 1000-10,987 (1951-1975)

These were usually preliminary or progress accounting documents intended for use within the government. Before material in the reports was formally published, it was subjected to additional evaluation and review. The reports were often called "graybacks" because of their gray covers.

NBS-GCR Reports
QC100.U6N25
70-1 to 88-550 (1970-1988).

NBS-GCR Reports
QC100.U6N25
88-551 to present.

Grantee/Contractor reports are prepared by non-NIST persons or organizations working under grant or contract from NIST.

NBS-GCR-ETIP Reports
73-01—82-101 (1973-1982)

Grantee/Contractor reports prepared by non-NBS persons or organizations working under grant or contract from NBS on subjects specifically for the Experimental Technology Incentives Program.

NBS Standard
T1.U44 Vol. 1—vol. 26, no. 15 (October 1955-July 22, 1981)

This publication was the official NBS employee newsletter. All department of commerce individual agency newsletters were discontinued in 1981 as part of the secretary of commerce's goal to develop a more unified and cohesive department. The assistant secretary for administration established an employee newsletter to cover the entire Department of Commerce.

NIST Building Science Series

This series disseminates technical information developed at NIST on building materials, components, systems, and whole structures. The series contains research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

Building Science Series
TA435.U58
No. 0-49 (1965-1974)
Continued by: NBS Building Science Series

NBS Building Science Series
TA435.U58
No. 50-165 (1974-1987)
Continues: Building Science Series
Continued by: NIST Building Science Series

NIST Building Science Series
TA435.U58
No. 166 (1989)—present
Continues: NBS Building Science Series

NIST Handbooks

These are recommended codes of engineering and industrial practice, including safety codes, developed in cooperation with the national organizations and others concerned. In many cases the recommended requirements are given official status through their incorporation in local ordinances by State and municipal regulatory bodies.

Handbook of the Bureau of Standards
QC1.U51
No. 1-18 (1918-1934)
Continued by: NBS Handbook

NBS Handbook
QC1.U51
No. 19-145 (1934-1986)
Continues: Handbook of the Bureau of Standards
Continued by: NIST Handbook

NIST Handbook
QC1.U51
No. 146 (1989)–present
Continues: NBS Handbook

NIST Monographs

Monographs are usually contributions to the technical literature which are too lengthy for publication in the *Journal of Research.* They often provide extensive compilations of information on subjects related to the Bureau's technical program. Until July 1959 most of this type of material was published in the Circular series.

NBS Monograph
QC100.U556
No. 1-174 (1959-1986)
Supersedes: National Bureau of Standards Circular
Continued by: NIST Monograph

NIST Monograph
QC100.U556
No. 175 (Approved 1990)—present.
Continues: NBS Monograph

NIST Special Publications

The Miscellaneous Publications series included material, which, because of its character or because of its size, did not fit into any of the other regular publication series. Some of these were charts, administrative pamphlets, directories of specifications, annual reports, weights and measures conference reports, and other subjects appropriate to this series. In 1968, the series title changed to Special Publication.

Miscellaneous Publication—Bureau of Standards
QC100.U57
No. 1-132 (1918-1933)
Continued by: Bureau of Standards Miscellaneous Publication

Bureau of Standards Miscellaneous Publication
QC100.U57
No. 133-144 (1932-1934)
Continues: Miscellaneous Publication—Bureau of Standards
Continued by: Miscellaneous Publication—National Bureau of Standards

Miscellaneous Publication—National Bureau of Standards
QC100.U57
No. 145-294 (1934-1967)
Continues: Bureau of Standards Miscellaneous Publication
Continued by: NBS Special Publication

NBS Special Publication
QC100.U57
No. 295-749 (1968-1988)
Continues: Miscellaneous Publication—National Bureau of Standards
Continued by: NIST Special Publication

NIST Special Publication
QC100.U57
No. 750 (1988)—present
Continues: NBS Special Publication

NIST TECHNICAL NOTES

This series was initiated in 1959 to supplement the Bureau's regular publications program. Technical Notes provide a means for making available scientific data that are of transient or limited interest.

NBS Technical Note
QC100.U5753
No. 1-1321 (1959-1988)
Continued by: NIST Technical Note
Nos. 1250-1299, 1310, 1318 published as NIST Technical Notes.

NIST Technical Note
QC100.U5753
No. 1250 (1988)—present
Continues: NBS Technical Note
Nos. 1300-1309, 1311-1317, 1319-1321 published as NBS Technical Notes.

NISTIR

This is a special series of interim or final reports on work performed by NIST for outside sponsors (both government and nongovernment).

NBSIR
QC100.U56
No. 73-101—88-3836 (1973-1988)

NISTIR
QC100.U56
NO. 88-3837 (1988)—present

NSRDS-NIST

The National Standard Reference Data Series provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. It was developed under a worldwide program coordinated by NBS, under authority of the National Standard Data Act (Public Law 90-396). This series supplements the *Journal of Physical and Chemical Reference Data.*

NSRDS-NBS
QC100.U573
No. 1-73 (1964-1987)
Continued by: NSRDS-NIST

NSRDS-NIST
QC100.U573
As of 7/7/99, nothing has been published in the NSRDS-NIST series.
Continues: NSRDS-NBS

Photographic Laboratory Circulars
TR395.U5
No. 1-2 (????-1920)

These were confidential reports of NBS tests for government agencies that were done in the Photographic Laboratory.

Planning Report
QC100.U5P5
No. 1 (1980)– present

These are internal reports but shared with government or private agencies. The reports are prepared by the NBS/NIST Program Office or by private contractors.

Product Standards *see* Voluntary Product Standards

Projects and Publications of the Applied Mathematics Division: a Quarterly Report

These were reports on the research and services of Division 11, the National Applied Mathematics Division.

Activities in Applied Mathematics
QA27.U5A31
(1946-1947)
Continued by: Projects and Publications of the National Applied Mathematics Laboratories: a Quarterly Report

Projects and Publications of the National Applied Mathematics Laboratories: a Quarterly Report
QA27.U5A32
(1947-1954)
Continues: Activities in Applied Mathematics
Continued by: Projects and Publications of the Applied Mathematics Division: a Quarterly Report

Projects and Publications of the Applied Mathematics Division: a Quarterly Report
QA27.U5A32
(1954-1964)
Continues: Projects and Publications of the National Applied Mathematics Laboratories: a Quarterly Report

REFERENCE DATA REPORTS

This was an informal communication of the National Standard Reference Data System (NSRDS) for the exchange of news and ideas about data centers, publications, meetings, and other activities related to data evaluation and dissemination. It ceased publication in April 1983.

NSRDS News
QC100.U57315
Issues for June 1966-May 1973 were originally published in the *Technical News Bulletin;* not published Nov. 1974-Apr. 1975, Mar., June-Aug. 1976
June 1973—Nov./Dec. 1976
Superseded by: Reference Data Report

Reference Data Report
QC100.U57315
Vol. 1-7 (1977-April 1983)
Other title: NSRDS Reference Data Report
Supersedes: NSRDS News

Reports *see* National Bureau of Standards Reports

Scientific Papers of the Bureau of Standards *see* Journal of Research

Simplified Practice Recommendations
QC100.U564
No. 1-80 (1922-1928)
(1928-1966)

"Simplified Practice," in this series, meant reduction of excessive variety of manufactured products, or of methods. Simplified Practice Recommendations were records of stock items retained after superfluous variety had been eliminated. These recommendations were developed by voluntary cooperation among manufacturers, distributors, consumers, and others interested, through a regular procedure of the National Bureau of Standards established for that purpose—a procedure designed to insure not only the initial success of a program, but also its continued adjustment to meet changing industrial conditions.

Each printed booklet contained not only the specific recommendation itself, but also its history and development, the names of trade associations, firms, individuals, and others that approved the recommendation, and the personnel of the standing committee in charge of its maintenance and revisions as needed to keep them current with developments. The date from which each recommendation was effective was given. Beginning in 1966 as they were revised, Simplified Practice Recommendations changed to Product Standards and later to Voluntary Product Standards.

Standards Yearbook

QC100.U576

(1927-1933)

This publication gave a summary of progress in the field of standardization in agencies, both governmental and private, throughout the world. The yearbook was originally designed as a companion volume to "Commerce Yearbook." The seven volumes were published as Miscellaneous Publications 77, 83, 91, 106, 119, 133, 139 but titled Standards Yearbook.

Technical Information on Building Materials for Use in the Design of Low Cost Housing

TH1.U5

No. 1-61 (1936-1938)

These releases presented, very briefly, essential facts developed through research work at NBS and refer to longer publications where methods of investigation and results obtained were given in greater detail. They were prepared principally for the guidance of architectural and engineering staffs of federal agencies in the selection of materials for use in low-cost housing.

Technical Notes *see* NIST Technical Notes

Technologic Papers of the Bureau of Standards *see* Journal of Research

VOLUNTARY PRODUCT STANDARDS

This series provides requirements for sizes, types, quality and methods for testing various industrial products. These standards are developed cooperatively with interested government and industry groups, provide the basis for common understanding of product characteristics for both buyers and sellers, and are used voluntarily. Voluntary Product Standards include Commercial Standards (material requirements and quality criteria) and Simplified Practice Recommendations (sizes, models, and dimensions of commonly stocked items) revised since 1966. They are developed under procedures published by the Department of Commerce in Part 10, Title 15, of the "Code of Federal Regulations." The purpose of these standards is to establish nationally recognized requirements for products, and to provide all concerned interests with a basis for common understanding of the characteristics of the products. The National Institute of Standards and Technology administers the Voluntary Product Standards program as a supplement to the activities of the private sector standardizing organizations.

In 1979, private standards-writing organizations were encouraged by the Department of Commerce to develop voluntary product standards and it announced the withdrawal of all Voluntary Product Standards sponsored by NBS. Sponsorship of the standards was transferred to other institutions or private standards-writing organizations, or the standards were withdrawn. As of September 1997, three Voluntary Product Standards are still sponsored by NIST, but on a cost-reimbursable basis by private organizations.

Product Standards

QC100.U563

No. 0-13 (1966-1969)

Continued by: Voluntary Product Standards

Voluntary Product Standards

QC100.U563

No. 14 (1969)—present

Continues: Product Standards

APPENDIX K

STRUCTURE AND LEADERSHIP OF NBS/NIST

Substantial changes in the NBS/NIST administrative structure occurred over the years 1901-1991. These changes are illustrated here by selections from the organizational charts for the years 1905, 1920, 1930, 1940, 1950, 1954, 1964, 1978, and 1991.

TREASURY DEPARTMENT.
Office of Disbursing Clerk.

Duplicate

PAY ROLL.

We, the Subscribers, acknowledge to have received from GEO. A. BARTLETT, *Disbursing Clerk, Treasury Department, the sums opposite our respective names, in full of our Salaries in the Office of* National Bureau of Standards, *for the month ending* July 31st, 1901.

Jul. 31-1901

NAMES.	CAPACITY.	ANNUAL SALARY.	AMOUNT OF SALARY.	SIGNATURES.
S. W. Stratton	Director	5000	421 20	
Edward B. Rosa	Physicist	3500	294 80	
Louis A. Fischer	Asst. Physicist	2200	185 30	
Frank A. Wolff, Jr.	" "	2200	185 30	
Otto Storm	Mechanician	1400	117 90	pd.
Arthur F. Belitz	Clerk	1200	101 10	pd.
J. A. McDowell	Watchman	720	60 60	
George Newman	Messenger	720	60 60	pd.
Geo. H. Draper	Labourer	600	50 50	
C. E. Richards	Laboratory Asst.	1400	26 63	
Miss R. S. Sliney	" "	1200	78 26	pd.
Sidney F. Jones	" "	1400	45 65	pd.

Correct:
(Sgd) S. W. Stratton,
Director.

Approved:
(Sgd) Chas Lyman
Chief, Division of Appointments.

One of the first official payrolls of NBS, July 1901.

The Bureau structure on July 1, 1905 showed the rapid progress made by Director Samuel Stratton in creating a core structure for NBS.

JULY 1, 1905

DIRECTOR	Dr. Samuel W. Stratton
WEIGHTS AND MEASURES	Louis A. Fischer
Comparison of Capacities	Roy Y. Ferner
Weights and Measures Assistant	Arthur T. Pienkowsky
HEAT AND THERMOMETRY	Dr. Charles W. Waidner
Low Temperature Investigations	Dr. Charles W. Waidner
High Temperature Investigations	Dr. George K. Burgess
Comparison of Thermometers	Dr. Hobart C. Dickinson
Heat and Thermometry Assistant	Eugene F. Mueller
LIGHT AND OPTICAL INSTRUMENTS	Dr. Samuel W. Stratton
Spectroscopy	Dr. Perley G. Nutting
Magneto-Optics	Frederick J. Bates
Computer	Dr. William W. Coblentz
ENGINEERING INSTRUMENTS AND MATERIALS	Charles F. Sponsler
Engineering Instruments and Materials Assistants	Albert S. Merrill
	Oscar G. Lange
ELECTRICITY	Dr. Edward B. Rosa
Inductance and Capacity	Dr. Edward B. Rosa
	Dr. Frederick W. Grover
Magnetism and Absolute Measurements of Current	Dr. Karl E. Guthe
Electrical Measuring Instruments	Herbert B. Brooks
	Dr. Morton G. Lloyd
	Clarence E. Reid
Photometry	Dr. Edward P. Hyde
Electrical Resistance and Electromotive Force	Dr. Frank A. Wolff
	Dr. George W. Middlekauff
Electricity Assistants	Francis E. Cady
	Franklin S. Durston
	Dr. N. Ernest Dorsey
	Maynard P. Shoemaker
Naval Radio Research Laboratory	Dr. Louis W. Austin
Army Signal Service Radio Laboratory	E.R. Cramm
CHEMISTRY	Dr. William A. Noyes
Chemistry Assistants	Dr. Henry N. Stokes
	Dr. John R. Cain
	Campbell E. Waters

* * *

The Bureau structure on January 1, 1920 showed the increased breadth of its program near the end of Samuel Stratton's tenure and after strenuous contributions to military technology during World War I.

JANUARY 1, 1920

DIRECTOR	Dr. Samuel W. Stratton
Technical Assistant to the Director	Dr. Fay C. Brown
I. ELECTRICAL	Dr. Edward B. Rosa
Standards of Resistance	Dr. Frank Wenner
Inductance and Capacity	Dr. Harvey L. Curtis
Electrical Measuring Instruments	Dr. Herbert B. Brooks
Magnetic Measurements	Raymond L. Sanford
Photometry and Illuminating Engineering	Dr. A. Hadley Taylor
Radio Research and Testing	Dr. J. Howard Dellinger
Radio Development	Frederick A. Kolster
Electrolysis Prevention	Burton McCollum
Safety Engineering	Dr. Morton G. Lloyd
Gas Engineering	Russell S. McBride
Electrical Service Standards	Dr. J. Franklin Meyer
Telephone Service Standards	Dr. Frank A. Wolff
Electrochemistry	Dr. George W. Vinal
Radioactivity and X-ray Measurements	Dr. N. Ernest Dorsey
II. WEIGHTS AND MEASURES	Louis A. Fischer
Length	Dr. Lewis V. Judson
Mass	Dr. Arthur T. Pienkowsky
Time	Arthur F. Beal
Capacity and Density	Elmer L. Peffer
Gas Measuring Instruments	Marcus H. Stillman
Thermal Expansivity	Dr. Wilmer Souder
Weights and Measures Laws and Administration	Fay S. Holbrook
Investigation and Testing of Scales	Fay S. Holbrook
Gages	Henry W. Bearce
III. HEAT AND THERMOMETRY	Dr. Charles W. Waidner
Thermometry	Robert M. Wilhelm
Pyrometry	Dr. Paul D. Foote
Heat Measurements	Eugene F. Mueller
Thermodynamics	Dr. Edgar Buckingham
Cryogenic Laboratory	Clarence W. Kanolt
Fire Resistance	Simon H. Ingberg
Airplane and Automotive Power Plant	Dr. Hobart C. Dickinson
IV. LIGHT AND OPTICAL INSTRUMENTS	Dr. Clarence A. Skinner
Spectroscopy	Dr. William F. Meggers
Polarimetry	Frederick J. Bates
Colorimetry	Irwin G. Priest
Refractometry and Optical Instruments	Harry I. Schultz
Radiometry	Dr. William W. Coblentz
Dispersoids	Dr. Philip V. Wells
Photographic Technology	Planned
Interferometry	Chauncey G. Peters
Searchlight Investigations	Enoch Karrer

V. Chemistry	Dr. William F. Hillebrand
Physical Chemistry	Dr. Cyril S. Taylor
Electrochemistry	Dr. William Blum
Metallurgical Chemistry	Dr. John R. Cain
Gas Chemistry	Elmer R. Weaver
Reagents and Apparatus	Frederick W. Smither
Analytical Methods, Standard Samples	Dr. Gustave E.F. Lundell
Oils, Rubber, Paper, etc.	Campbell E. Waters
Metals, Cement, Bituminous Materials	Samuel S. Voorhees
Paint, Varnish, Soap	Dr. Percy H. Walker
VI. Engineering Physics	Dr. Samuel W. Stratton
Mechanical Appliances	Philip L. Wormeley
Engineering Instruments	Walter F. Stutz
Aviation Instruments	Dr. Mayo D. Hersey
Aviation Physics	Dr. Lyman J. Briggs
Special Investigations (Sound)	John F. Hayford
VII. Engineering, Structural, and Miscellaneous Materials	Dr. Samuel W. Stratton
Metal Structures	Herbert L. Whittemore
Cement, Sand, Stone, etc.	Joseph C. Pearson
Rubber, Leather, etc.	Philip L. Wormeley
Textiles	Frank R. McGowan
Paper	Frederick A. Curtis
Lubricating Oils	Dr. Winslow H. Herschel
Lime, Gypsum, Sand, Brick	Warren E. Emley
VIII. Metallurgy	Dr. George K. Burgess
Microscopy of Metals	Dr. Henry S. Rawdon
Heat Treatment and Thermal Analysis	Herbert J. French
Physical Properties of Metals	Dr. George K. Burgess
Chemical Metallurgy	Dr. John R. Cain
Foundry and Mechanical Plant	Carydon P. Karr
IX. Ceramics	Dr. Albert V. Bleininger
Clay Products	Dr. Albert V. Bleininger
Optical Glass	William H. Taylor
Refractories	Homer F. Staley
Enameled Metal Products	Homer F. Staley
X. Miscellaneous (Sound)	Dr. Englehardt A. Eckhardt

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By April 1, 1930, George K. Burgess had further expanded the Bureau's horizon, particularly in the area of building construction.

APRIL 1, 1930

DIRECTOR	Dr. George K. Burgess
Assistant Director for Research and Testing	Dr. Lyman J. Briggs
Assistant Director for Commercial Standardization	Dr. Addams S. McAllister
I. Electrical	Dr. Eugene C. Crittendon
Resistance Measurements	Dr. Frank Wenner
Inductance and Capacitance	Dr. Harvey L. Curtis
Electrical Instruments	Dr. Herbert B. Brooks

Magnetic Measurements	Raymond L. Sanford
Photometry	Dr. J. Franklin Meyer
Radio	Dr. J. Howard Dellinger
Underground Corrosion	Kirk H. Logan
Safety Standards	Dr. Morton G. Lloyd
Electrochemistry	Dr. George W. Vinal
Telephone Standards	Dr. Frank A. Wolff
II. WEIGHTS AND MEASURES	Fay S. Holbrook and Henry W. Bearce
Length	Dr. Lewis V. Judson
Mass	Dr. Arthur T. Pienkowsky
Time	Ralph E. Gould
Capacity and Density	Elmer L. Peffer
Gas Measuring Instruments	Howard S. Bean
Thermal Expansivity	Dr. Wilmer Souder
Weights and Measures Laws and Administration	Ralph W. Smith
Railroad Scales and Test Cars	Fay S. Holbrook
Gages	David R. Miller
III. HEAT AND POWER	Dr. Hobart C. Dickinson
Thermometry	Johanna Busse
Pyrometry	Dr. Henry T. Wensel
Heat Measurements	Eugene F. Mueller
Heat Transfer	Dr. Milton S. VanDusen
Cryogenic Laboratory	Dr. Ferdinand G. Brickwedde
Fire Resistance	Simon H. Ingberg
Automotive Power Plant	Herbert K. Cummings
Friction and Lubrication	Dr. Mayo D. Hersey
IV. OPTICS	Dr. Clarence A. Skinner
Spectroscopy	Dr. William F. Meggers
Polarimetry	Frederick J. Bates
Colorimetry	Irwin G. Priest
Optical Instruments	Dr. Irvine C. Gardner
Radiometry	Dr. William W. Coblentz
Atomic Physics, Radium, X-Rays	Dr. Fred L. Mohler
Photographic Technology	Raymond Davis
Interferometry	Chauncey G. Peters
V. CHEMISTRY	Dr. Edward W. Washburn
Physico-Chemical Research	Dr. Edward W. Washburn
Paints, Varnish, Bituminous Materials	Dr. Percy H. Walker
Detergents, Cement, Corrosion	Frederick W. Smither
Rubber, Lubricants, Textiles	Campbell E. Waters
Metal and Ore Analysis, Standard Samples	Dr. Gustave E. F. Lundell
Reagents and Platinum Metals	Dr. Edward Wichers
Electrochemistry	Dr. William Blum
Gas Chemistry	Elmer R. Weaver

VI. MECHANICS AND SOUND	Dr. Lyman J. Briggs
Engineering Instruments and Mechanical Appliances	Walter F. Stutz
Sound	Dr. Paul R. Heyl
Aeronautic Instruments	Dr. William G. Brombacher
Aerodynamic Physics	Dr. Hugh L. Dryden
Engineering Mechanics	Herbert L. Whittemore
Hydraulic Laboratory	Herbert N. Eaton
VII. ORGANIC AND FIBROUS MATERIALS	Warren E. Emley
Rubber	Philip L. Wormeley
Textiles	William D. Appel
Paper	Bourdon W. Scribner
Leather	Roy C. Bowker
VIII. METALLURGY	Dr. Henry S. Rawdon
Optical Metallurgy	Dr. Henry S. Rawdon
Thermal Metallurgy	Dr. Ralph L. Dowdell
Mechanical Metallurgy	William H. Swanger
Chemical Metallurgy	Louis Jordan
Experimental Foundry	Charles M. Saeger, Jr.
IX. CLAY AND SILICATE PRODUCTS	Phaon H. Bates
Whiteware	Roman F. Geller
Glass	Alfred N. Finn
Refractories	Raymond A. Heindl
Enamels	William N. Harrison
Heavy Clay Products	Ray T. Stull
Cement and Concrete Materials	John Tucker, Jr.
Masonry Construction	Douglas E. Parsons
Lime and Gypsum	James A. Murray
Stone	Daniel W. Kessler
X. SIMPLIFIED PRACTICE	Edwin W. Ely
Stone, Clay, and Glass	Herbert R. Colwell
Wood, Textiles, and Paper	George Schuster
Metal Products and Construction Materials	Peter H. H. Dunn
Containers	William E. Braithwaite
Promotion and Adherence	Alexander B. Galt
XI. BUILDING AND HOUSING	James S. Taylor
Building Codes	George N. Thompson
Building Practice and Homebuilders' Problems	Vincent B. Phelan
City Planning and Zoning	James S. Taylor
Construction Economics	Dr. John R. Riggleman
Mechanics Liens	Daniel H. Wheeler
XII. SPECIFICATIONS	Dr. Addams S. McAllister
Certification: Producer Contacts	Robert A. Martino
Labeling: Consumer Contacts	Dr. Addams S. McAllister
Directory of Specifications	Clarence W. Ingels
Encyclopedia of Specifications	George A. Wardlaw

XIII. **Trade Standards**	Ihler J. Fairchild
Wood Products, Paper, Rubber, etc.	Harry H. Steidle
Metal Products	Ihler J. Fairchild
Textiles and Garments	Ihler J. Fairchild
Ceramic Products and Cement	George W. Wray

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By May 1, 1940, dental research and field stations had become part of the NBS technical program.

MAY 1, 1940

Director	Dr. Lyman J. Briggs
Assistant to the Director	Henry D. Hubbard
Assistant Director for Research and Testing	Dr. Eugene C. Crittendon
Assistant Director for Commercial Standardization	Dr. Addams S. McAllister
I. **Electricity**	Dr. Eugene C. Crittendon
Resistance Measurements	Dr. Frank Wenner
Inductance and Capacitance	Dr. Harvey L. Curtis
Electrical Instruments	Dr. Francis B. Silsbee
Magnetic Measurements	Raymond L. Sanford
Photometry	Dr. J. Franklin Meyer
Radio	Dr. J. Howard Dellinger
Underground Corrosion	Kirk H. Logan
Electrochemistry	Dr. George W. Vinal
Telephone Standards	Dr. Frank A. Wolff
II. **Weights and Measures**	Henry W. Bearce
Length	Dr. Lewis V. Judson
Mass	Dr. Arthur T. Pienkowsky
Time	Ralph E. Gould
Capacity and Density	Elmer L. Peffer
Gas Measuring Instruments	Howard S. Bean
Thermal Expansion, Dental Research	Dr. Wilmer Souder
Weights and Measures Laws and Administration	Ralph W. Smith
Large-Capacity Scales	Ralph W. Smith
Gages	David R. Miller
III. **Heat and Power**	Dr. Hobart C. Dickinson
Thermometry	Johanna Busse
Pyrometry	Dr. Henry T. Wensel
Heat Measurements	Eugene F. Mueller
Heat Transfer	Dr. Milton S. VanDusen
Cryogenic Laboratory	Dr. Ferdinand G. Brickwedde
Fire Resistance	Simon H. Ingberg
Automotive Power Plants	Herbert K. Cummings
Lubrication and Liquid Fuels	Dr. Oscar C. Bridgeman
Aviation Engines and Accessories	Melville F. Peters

IV. Optics	Dr. Clarence A. Skinner
Spectroscopy	Dr. William F. Meggers
Polarimetry	Frederick J. Bates
Colorimetry and Spectrophotometry	Dr. Kasson S. Gibson
Optical Instruments	Dr. Irvine C. Gardner
Radiometry	Dr. William W. Coblentz
Atomic Physics, Radium, X-Rays	Dr. Fred L. Mohler
Photographic Technology	Raymond Davis
Interferometry Chauncey	G. Peters
V. Chemistry	Dr. Gustave E.F. Lundell
Paints, Varnishes, etc.	Eugene F. Hickson
Detergents, Cement, etc.	Frederick W. Smither
Organic Chemistry	Campbell C. Waters
Metal and Ore Analysis, Standard Samples	Harry A. Bright
Reagents and Platinum Metals	Dr. Edward Wichers
Electrochemistry (Plating)	Dr. William Blum
Gas Chemistry	Elmer R. Weaver
Physical Chemistry	Dr. Edgar R. Smith
Thermochemistry and Constitution of Petroleum	Dr. Frederick D. Rossini
VI. Mechanics and Sound	Dr. Hugh L. Dryden
Engineering Instruments	Walter F. Stutz
Sound	Dr. Paul R. Heyl
Aeronautical Instruments	Dr. William G. Brombacher
Aerodynamic Physics	Dr. Hugh L. Dryden
Engineering Mechanics	Herbert L. Whittemore
Hydraulics	Herbert N. Eaton
VII. Organic and Fibrous Materials	Warren E. Emley
Rubber	Dr. Archibald T. McPherson
Textiles	William D. Appel
Paper	Bourdon W. Scribner
Leather	Roy C. Bowker
Testing and Specifications	Philip L. Wormeley
Fiber Structure	Dr. Solomon F. Acree
Organic Plastics	Dr. Gordon M. Kline
VIII. Metallurgy	Dr. Henry S. Rawdon
Optical Metallurgy	Dr. Henry S. Rawdon
Thermal Metallurgy	Dr. Dunlop J. McAdam, Jr.
Mechanical Metallurgy	William H. Swanger
Chemical Metallurgy	Dr. John G. Thompson
Experimental Foundry	Charles M. Saeger, Jr.

IX. Clay and Silicate Products	Phaon H. Bates
Whiteware	Roman F. Geller
Glass	Alfred N. Finn
Refractories	Raymond A. Heindl
Enameled Metals	William N. Harrison
Heavy Clay Products	Ray T. Stull
Cement and Concrete Materials	John Tucker, Jr.
Masonry Construction	Douglas E. Parsons
Lime and Gypsum	Dr. Lansing S. Wells
Stone	Daniel W. Kessler
X. Simplified Practice	Edwin W. Ely
Wood, Textiles, and Paper	George Schuster
Metal Products and Construction Materials	George Schuster
Containers and Miscellaneous Products	William E. Braithwaite
Materials Handling Equipment and Ceramics	Edwin W. Ely
XI. Trade Standards	Ihler J. Fairchild
Wood, Wood Products, etc.	James W. Medley
Metal Products	Ihler J. Fairchild
Textiles	Herbert A. Ehrman
Apparel	Lovic R. Gilbert
Petroleum, Chemicals, Rubber	Floyd W. Reynolds
Export Standards	Milton E. Countryman
XII. Codes and Specifications	Dr. Addams S. McAllister
Safety Codes	Dr. Morton G. Lloyd
Building Codes	George N. Thompson
Building Practice and Specifications	Vincent B. Phelan
Producer Contracts and Certification	George W. Wray
Consumer Contracts and Labeling	Robert A. Martino
Field Stations	
Allentown, Pa. (Cement and Concrete Materials)	William N. Moyer
Riverside, Calif. (Cement and Concrete Materials)	Donald N. Evans
San Francisco, Calif. (Cement and Concrete Materials)	I. Furlong
Denver, Colo. (Cement and Concrete Materials)	Orson H. Cox
Seattle, Wash. (Cement and Concrete Materials)	Elmer T. Carlson
Clearing, Ill. (Large-capacity Scale Testing)	C. L. Richard
San Jose, Calif. (Cement and Concrete Materials)	Bruce E. Foster
Beltsville, Md. (Radio Transmitting Station)	William D. George
Meadows, Md. (Radio Sending Station)	Samuel S. Kirby

* * *

By March 1, 1950, the demands on NBS of World War II and the introduction of computers were evident in the Bureau structure.

MARCH 1, 1950

	DIRECTOR'S OFFICE	
	Director	Dr. Edward U. Condon
	Assistant to the Director	Hugh Odishaw
	Assistant to the Director	Nicholas E. Golovin
	Associate Director	Dr. Eugene C. Crittenden
	Associate Director	Dr. Wallace R. Brode
	OFFICE OF SCIENTIFIC PUBLICATIONS	Hugh Odishaw
	.1 Library	Sarah Ann Jones
	.2 Technical Reports	W. Reeves Tilley
	.3 Publications	Jesse L. Mathusa
	OFFICE OF WEIGHTS AND MEASURES	Ralph W. Smith
	Assistant Chief	William S. Bussey
1	ELECTRICITY AND OPTICS	Dr. Francis B. Silsbee
	Assistant Chief	Dr. Kasson S. Gibson
	.1 Resistance Measurements	Dr. James L. Thomas
	.2 Inductance and Capacitance	Dr. Charles Moon
	.3 Electrical Instruments	Dr. Francis M. Defandorf
	.4 Magnetic Measurements	Raymond L. Sanford
	.5 Photometry and Colorimetry	Dr. Kasson S. Gibson
	.6 Optical Instruments	Dr. Irvine C. Gardner
	.7 Photographic Technology	Raymond Davis
	.8 Electrochemistry	Dr. George W. Vinal
2	METROLOGY	Dr. Wilmer Souder
	Assistant Chief	David R. Miller
	.1 Length	Dr. Lewis V. Judson
	.2 Mass	Lloyd B. Macurdy
	.3 Time	Horace A. Bowman (Acting)
	.4 Capacity, Density and Fluid Meters	Howard S. Bean
	.6 Thermal Expansion	Dr. Peter Hidnert
	.7 Dental Materials	Dr. Irl C. Schoonover
	.8 Scales	H. Haig Russell
	.9 Gages	David R. Miller
3	HEAT AND POWER	Dr. Ferdinand G. Brickwedde
	.1 Temperature Measurements	Dr. Raymond E. Wilson
	.2 Thermodynamics	Dr. Ferdinand G. Brickwedde
	.3 Cryogenics	Russell B. Scott
	.4 Engines and Lubrication	Samuel A. McKee
	.5 Engine Fuels	Dr. Frank L. Howard (Acting)
	.6 Combustion	Dr. Ernest F. Fiock

4	**ATOMIC AND RADIATION PHYSICS**		Dr. Robert D. Huntoon
	Assistant Chief		Lauriston S. Taylor
	Radioactivity Consultant		Dr. Leon F. Curtiss
	Stable Tracers Consultant		Dr. Fred L. Mohler
4A	**Atomic Physics Laboratory**		Dr. Robert D. Huntoon
	.1	Spectroscopy	Dr. William F. Meggers
	.2	Radiometry	Dr. Curtis J. Humphreys
	.3	Mass Spectrometry	Dr. Fred L. Mohler
	.4	Physical Electronics	Dr. Willard H. Bennett
	.5	Electron Physics	Dr. Ladislaus L. Marton
	.6	Atomic Physics	Dr. John A. Hipple
	.7	Neutron Measurements	Dr. Leon F. Curtiss
4R	**Radiation Physics Laboratory**		Lauriston S. Taylor
	.8	Nuclear Physics	Dr. Ugo Fano
	.9	Radioactivity	Lauriston S. Taylor (Acting)
	.10	X-Rays	Harold O. Wyckoff
	.11	Betatron	Herman W. Koch
	.12	Nucleonic Instrumentation	Harold O. Wyckoff (Acting)
	.13	Radiological Equipment	Dr. Scott W. Smith
5	**CHEMISTRY**		Dr. Edward W. Wichers
	Assistant Chief		Dr. William Blum
	.1	Paint, Varnish and Lacquer	Eugene F. Hickson
	.2	Surface Chemistry	Dr. James I. Hoffman
	.3	Organic Chemistry	W. Harold Smith
	.4	Analytical Chemistry	Harry A. Bright
	.5	Platinum Metals and Pure Substances	Dr. Raleigh Gilchrist
	.6	Electrodeposition	Dr. William Blum
	.7	Gas Chemistry	Elmer R. Weaver
	.8	Physical Chemistry	Dr. Edgar R. Smith
	.9	Thermochemistry and Hydrocarbons	Dr. Frederick D. Rossini
	.10	Spectrochemistry	Bourdon F. Scribner
6	**MECHANICS**		Dr. Walter Ramberg
	.1	Sound	Dr. Richard K. Cook
	.2	Mechanical Instruments	Dr. William G. Brombacher
	.3	Aerodynamics	Dr. Galen B. Schubauer
	.4	Engineering Mechanics	Bruce L. Wilson
	.5	Hydraulics	Herbert N. Eaton
7	**ORGANIC AND FIBROUS MATERIALS**		Dr. Archibald T. McPherson
	Assistant Chief		Dr. Gordon M. Kline
	Consultant		Dr. Robert Simha
	.1	Rubber	Dr. Lawrence A. Wood
	.2	Textiles	William D. Appel
	.3	Paper	Bourdon W. Scribner
	.4	Leather	Everett L. Wallace
	.5	Testing and Specifications	Dr. Robert D. Stiehler
	.7	Organic Plastics	Dr. Gordon M. Kline
8	**METALLURGY**		Dr. John G. Thompson
	Assistant Chief		William F. Roeser
	.1	Optical Metallurgy	George A. Ellinger
	.2	Thermal Metallurgy	Thomas G. Digges

	.3 Mechanical Metallurgy	William F. Roeser
	.4 Chemical Metallurgy	Harold E. Cleaves
	.5 Experimental Foundry	Alexander I. Krynitsky
	.6 Underground Corrosion	Dr. Irving A. Denison
9	**MINERAL PRODUCTS**	Dr. Herbert Insley
	.1 Porcelain and Pottery	Roman F. Geller
	.2 Glass	Clarence H. Hahner
	.3 Refractories	Raymond A. Heindl
	.4 Enameled Metals	William N. Harrison
	.5 Building Stone	Daniel W. Kessler
	.6 Concreting Materials	Raymond L. Blaine
	.7 Constitution and Microstructure	Howard F. McMurdie
	.8 Chemistry of Mineral Products	Dr. Lansing S. Wells
10	**BUILDING TECHNOLOGY**	Douglas E. Parsons
	Assistant Chief	George N. Thompson
	.1 Structural Engineering	Douglas E. Parsons
	.2 Fire Protection	Nolan D. Mitchell
	.3 Heating and Air Conditioning	Richard S. Dill
	.4 Exterior and Interior Covering	Hubert R. Snoke
	.5 Codes and Specifications	George N. Thompson
11	**APPLIED MATHEMATICS**	Dr. John H. Curtiss
	Assistant Chief	Dr. Edward W. Cannon
	.1 Numerical Analysis	Dr. J. Berkley Rosser (UCLA)
	.2 Computation	Dr. Franz L. Alt (Acting)
	.3 Statistical Engineering	Dr. Churchill Eisenhart
	.4 Machine Development	Dr. Edward W. Cannon (Acting)
12	**COMMODITY STANDARDS**	Edwin W. Ely
	Assistant Chief	Floyd W. Reynolds
	.1 Metal and Ceramic Products	George Schuster
	.2 Textiles and Apparel	Herbert A. Ehrman
	.3 Mechanical Equipment	James W. Medley
	.4 Packaging	William E. Braithwaite
	.5 Chemical Products	Floyd W. Reynolds
13	**ELECTRONICS AND ORDNANCE**	Dr. Allen V. Astin
	Assistant Chief for Ordnance	Wilbur S. Hinman, Jr.
	Assistant Chief for Aerophysics	Dr. Harold K. Skramstad
	Electronics Consultant	Dr. Robert D. Huntoon
	Electronics Consultant	Dr. Chester H. Page
	Technical Aide	Robert S. Walleigh
	Electronic Standards Laboratory	(Vacant)
	.1 Engineering Electronics	Joseph G. Reid, Jr.
	.2 Electron Tubes	Dr. John E. White
	.3 Electronic Computers	Dr. Samuel N. Alexander
	Ordnance Development Laboratory	Wilbur S. Hinman, Jr.
	.4 Ordnance Research	Dr. Harold Goldberg
	.5 Ordnance Mechanics	Jacob Rabinow
	.6 Ordnance Electronics	P. Anthony Guarino
	.7 Ordnance Engineering	Myron G. Domsitz
	.8 Ordnance Tests	Theodore B. Godfrey

	Guided Missile Branch	Ralph A. Lamm
	.9 Missile Dynamics	Dr. Harold K. Skramstad
	.10 Missile Intelligence	Dr. Fred S. Atchison
	.11 Missile Engineering	Ralph A. Lamm
	.12 Missile Instrumentation	William A. Wildhack
	.13 Technical Services	James D. McLean (Acting)
14	CENTRAL RADIO PROPAGATION LABORATORY	Dr. Newbern Smith
	Assistant Chief	Alvin G. McNish
	Assistant Chief	Kenneth A. Norton
	Microwave Research Consultant	Dr. Thomas J. Carroll, Jr.
	Ionospheric Research Laboratory	
	.1 Upper Atmosphere Research	Alvin G. McNish
	.5 Ionospheric Research	Ross Bateman
	.7 Field Operations	Henry P. Hutchinson
	Systems Research Laboratory	
	.3 Regular Propagation Services	Walter B. Chadwick
	.4 Frequency Utilization Research	Kenneth A. Norton
	.6 Tropospheric Propagation Research	Jack W. Herbstreit (Acting)
	Measurement Standards Laboratory	
	.8 High Frequency Standards	William D. George
	.9 Microwave Standards	Dr. Harold Lyons
M	BUDGET AND MANAGEMENT	Herbert E. Weifenbach
	.1 Budget	Edward E. Upperman
	.2 Management Planning	Wilbur W. Bolton, Jr.
	.3 Procurement	Charles B. Kipps
	.4 Property Management	George B. Kefover
	.5 Records and Communications	Robert W. Lamberson
	.6 Accounting	Clinton G. Hall
	.7 Special Services	Frank D. Moncure (Acting)
P	PERSONNEL	Raymond L. Randall
	Assistant Chief	William C. Fewell
	.1 Recruitment and Placement	Raymond L. Randall
	.2 Operations	Jessie B. Berkley
	.3 Classification	Lawrence L. Epperson
	.4 Medical Office	Dr. William Frank
	.5 Education and Training	Joseph Hilsenrath
E	PLANT	William J. Ellenberger
	Assistant Chief	Oscar L. Britt
	.1 Power Plant	Grover F. Hamby
	.2 Electrical Shop	George V. Hall
	.3 Piping Shop	Raymond A. Watson
	.4 Carpenter Shop	Paul J. Robinson
	.5 Paint Shop	Raymond E. Mothershead
	.6 General Service	Frank A. Peters
	.7 Garage	Harry C. Magruder
	.8 Guard	Herman B. Burke
	.9 Grounds	William R. David
	.10 Janitorial	Adeeb J. Neam
	.11 Refrigeration and Air Conditioning	Elridge G. Burke
	.12 Administrative and Engineering Office	(Vacant)

S	**SHOPS**		Paul S. Ballif
	Assistant Chief		Winfield L. Drissel
	Shop Superintendent		John L. Hutton
	.1	Design and Drafting	Richard J. Hanrahan
	.2	Instrument Shop No. 1	Henry N. Philo
	.3	Instrument Shop No. 2	George A. Rheinbold
	.4	Instrument Shop No. 3	George W. Bicking, Jr.
	.5	Instrument Shop No. 4	Charles W. Hyder
	.6	Instrument Shop No. 5	Andrew J. Altman
	.7	Welding and Sheet Metal Shop	Edward G. Clark
	.8	Woodworking Shop	Paul D. Huntley
	.9	Shop Tools	Lewis H. Brigham
	.10	Maintenance	Winfield L. Drissel
	.11	Glassblowing Shop	Leonardo Testa
	.12	Metals Storeroom	James E. Mallory

FIELD STATIONS

1 **ELECTRICITY AND OPTICS**

Lamp Inspector, Brookline, MA
George Schnitzler

2 **METROLOGY**

Master Scale Depot, Clearing, IL
H. Haig Russell, Chief

9 **MINERAL PRODUCTS**

Cement Testing and Inspection Station, Allentown, PA
William N. Moyer, Chief

Cement Testing and Inspection Station, Riverside Cement Co., Riverside, CA
Donald N. Evans, Chief

Cement Testing and Inspection Station, Permanente Cement Co., Permanente, CA
Martin Defore, Chief

Cement Testing and Inspection Station, Sanitary Engineering Building, University of Washington, Seattle, WA
Frank N. Winblade, Chief

Cement and Concrete Materials Testing Station, Denver, CO
Orson H. Cox, Chief

Materials Testing Station, San Francisco, CA
Otto C. Marek (Acting) Chief

11 **APPLIED MATHEMATICS**

Institute for Numerical Analysis, University of California at Los Angeles, Los Angeles, CA
Dr. J. Berkley Rosser (Acting) Chief

13 **ELECTRONICS**

Blossom Point Proving Ground, La Plata, MD
Adrian P. Sutton, Chief

Warren Grove Test Field, Warren Grove, Tuckerton, NJ
William A. Wildhack, Chief

Radio Propagation Field Station, Anchorage, AK
Vernon H. Goerke, Chief

Radio Propagation Field Station, Point Barrow, AK
Lloyd A. Lohr, Chief

Radio Propagation Field Station, Island of Guam
Herschel C. Carmichael, Chief

Radio Propagation Field Station, Puunene, Maui, Territory of Hawaii
Leo W. Honea, Chief

Radio Propagation Field Station, Palmyra Island, Honolulu, Territory of Hawaii
Stephen S. Barnes, Chief (Acting)

Radio Propagation Field Station, Ramey Air Force Base, Puerto Rico
Theodore R. Gilliland, Chief

Radio Propagation Field Station, Trinidad, B. W. I.
Richard F. Carle, Chief

Radio Propagation Field Station, White Sands Proving Ground, Las Cruces, NM
Earl E. Ferguson, Chief

Radio Propagation Field Station, Ft. Belvoir, VA
Edward J. Wiewara, Chief

Radio Propagation Laboratory, Sterling, VA
Victor C. Pineo, Chief

Radio Transmitting Station, Beltsville, MD
Gordon H. Lester, Chief

The divestiture of the World War II military research groups—electronic standards laboratory, ordnance development laboratory, and guided missile branch—had been accomplished by October 1, 1954, under Director Allen Astin. By then, too, new laboratories had been created in Boulder, Colorado.

OCTOBER 1, 1954

	DIRECTOR'S OFFICE	
	Director	Dr. Allen V. Astin
	Associate Director for Chemistry	Dr. Wallace R. Brode
	Associate Director for Physics	Dr. Robert D. Huntoon
	Associate Director for Testing	Dr. Archibald T. McPherson
	Associate Director for Administration	Nicholas E. Golovin
	Director, Boulder Laboratories	Dr. Frederick W. Brown (Boulder)
	Consultant to the Director	Dr. Eugene C. Crittenden
	Consultant to the Director	Dr. Leon F. Curtiss
	Consultant to the Director	Dr. Chester H. Page
	Consultant to the Director	Dr. Wilmer Souder
	Consultant to the Director	Alvin G. McNish
	Security Officer	Dr. Robert D. Huntoon
	Program Records Officer	Clarence N. Coates
	OFFICE OF SCIENTIFIC PUBLICATIONS	Dr. Wallace R. Brode
	.1 Library	Sarah Ann Jones
	.2 Technical Reports	W. Reeves Tilley
	.3 Publications	Jesse L. Mathusa
	OFFICE OF WEIGHTS AND MEASURES	William S. Bussey
	Assistant Chief	Malcolm W. Jensen
	Consultant	Ralph W. Smith
	OFFICE OF BASIC INSTRUMENTATION	William A. Wildhack
	Assistant to the Chief	(Vacant)
1	**ELECTRICITY AND ELECTRONICS**	Dr. Francis B. Silsbee
	Assistant Chief for Electronics	Carroll Stansbury
	.1 Resistance and Reactance	Dr. James L. Thomas
	.2 Electron Tubes	Charles P. Marsden, Jr.
	.3 Electrical Instruments	Dr. Francis M. Defandorf
	.4 Magnetic Measurements	Irvin L. Cooter (Acting)
	.5 Process Technology	Lucien P. Tuckerman
	.6 Engineering Electronics	Dr. Paul J. Selgin
	.7 Electronic Instrumentation	Carroll Stansbury
	.8 Electrochemistry	Dr. Walter J. Hamer
2	**OPTICS AND METROLOGY**	Dr. Irvine C. Gardner
	Assistant Chief	Dr. Kasson S. Gibson
	Assistant to the Chief	Leroy W. Tilton
	.1 Photometry and Colorimetry	Dr. Kasson S. Gibson
	.2 Optical Instruments	Dr. Francis E. Washer
	.3 Photographic Technology	Raymond Davis
	.4 Length	Dr. Lewis V. Judson
	.5 Engineering Metrology	Irvin H. Fullmer

3	**HEAT AND POWER**	Dr. Ferdinand G. Brickwedde
	.1 Temperature Measurements	Dr. Ferdinand G. Brickwedde (Acting)
	.2 Thermodynamics	Dr. Charles W. Beckett
	.3 Cryogenics	Dr. Ralph P. Hudson (Acting)
	.4 Engines and Lubrication	James F. Swindells (Acting)
	.5 Engine Fuels	Dr. Frank L. Howard
4	**ATOMIC AND RADIATION PHYSICS**	Dr. Lauriston S. Taylor
4A	**Atomic Physics Laboratory**	
	.1 Spectroscopy	Dr. William F. Meggers
	.2 Radiometry	Dr. Earle K. Plyler
	.3 Mass Spectrometry	Dr. Fred L. Mohler
	.4 Solid State Physics	Dr. Robert G. Breckenridge
	.5 Electron Physics	Dr. Ladislaus L. Marton
	.6 Atomic Physics	Dr. Lewis M. Branscomb (Acting)
4R	**Radiation Physics Laboratory**	Dr. Harold O. Wyckoff
	.8 Nuclear Physics	Dr. Ugo Fano
	.9 Radioactivity	Dr. Wilfrid B. Mann
	.10 X-Rays	Dr. Harold O. Wyckoff
	.11 Betatron	Dr. Herman W. Koch
	.12 Nucleonic Instrumentation	Louis Costrell
	.13 Radiological Equipment	Dr. Scott W. Smith
	.14 Radiation Instruments Branch, Atomic Energy Commission	Robert L. Butenhoff
5	**CHEMISTRY**	Dr. Edward Wichers
	Assistant Chief	Dr. James I. Hoffman
	.1 Organic Coatings	Paul T. Howard
	.2 Surface Chemistry	Dr. James I. Hoffman
	.3 Organic Chemistry	W. Harold Smith
	.4 Analytical Chemistry	Harry A. Bright
	.5 Inorganic Chemistry	Dr. Raleigh Gilchrist
	.6 Electrodeposition	Dr. Abner Brenner
	.7 Gas Chemistry	Elmer R. Weaver
	.8 Physical Chemistry	Dr. Edgar R. Smith
	.9 Thermochemistry	Edward J. Prosen
	.10 Spectrochemistry	Bourdon F. Scribner
	.11 Pure Substances	Dr. Charles P. Saylor
6	**MECHANICS**	Dr. Walter Ramberg
	Consultant	Dr. Wilmer Souder
	.1 Sound	Dr. Richard K. Cook
	.2 Mechanical Instruments	Edward C. Lloyd
	.3 Fluid Mechanics	Dr. Galen B. Schubauer
	.4 Engineering Mechanics	Bruce L. Wilson
	.6 Mass and Scale	Douglas R. Tate
	.7 Capacity, Density and Fluid Meters	Howard S. Bean
	.8 Combustion Controls	Dr. Ernest F. Fiock

7	**Organic and Fibrous Materials**	Dr. Gordon M. Kline
	Assistant Chief	William D. Appel
.1	Rubber	Dr. Lawrence A. Wood
.2	Textiles	William D. Appel
.3	Paper	Dr. Robert B. Hobbs
.4	Leather	Everett L. Wallace
.5	Testing and Specifications	Dr. Robert D. Stiehler
.6	Polymer Structure	Dr. Norman P. Bekkedahl
.7	Organic Plastics	Frank W. Reinhart
.8	Dental Research	William T. Sweeney
8	**Metallurgy**	Dr. John G. Thompson
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.2	Chemical Metallurgy	Leroy L. Wyman
.3	Mechanical Metallurgy	John A. Bennett
.4	Corrosion	George A. Ellinger
9	**Mineral Products**	Dr. Irl C. Schoonover
	Assistant Chief	Clarence H. Hahner
.1	Porcelain and Pottery	Roman F. Geller
.2	Glass	Clarence H. Hahner
.3	Refractories	Raymond A. Heindl
.4	Enameled Metals	William N. Harrison
.6	Concreting Materials	Raymond L. Blaine
.7	Constitution and Microstructure	Howard F. McMurdie
10	**Building Technology**	Douglas E. Parsons
	Assistant Chief	George N. Thompson
	Consultant	William F. Roeser
	Consultant	John W. McBurney
.1	Structural Engineering	Douglas E. Parsons
.2	Fire Protection	Dr. Alexander F. Robertson
.3	Heating and Air Conditioning	Richard S. Dill
.4	Floor, Roof and Wall Coverings	Dr. Hubert R. Snoke
.5	Codes and Specifications	George N. Thompson
11	**Applied Mathematics**	Dr. Franz L. Alt (Acting)
	Assistant Chief	Dr. Edward W. Cannon
.1	Numerical Analysis	John Todd
.2	Computation	Dr. Milton Abramowithz (Acting)
.3	Statistical Engineering	Dr. Churchill Eisenhart
.4	Machine Development	Dr. Edward W. Cannon
12	**Data Processing Systems**	Samuel N. Alexander
	Assistant Chief for Systems	Dr. Harold K. Skramstad
.1	Components and Techniques	Arthur W. Holt
.2	Digital Circuitry	Robert D. Elbourn
.3	Digital Systems	Alan L. Leiner
.4	Analog Systems	Dr. Harold K. Skramstad (Acting)

40	**ACCOUNTING**	Gordon D. Horsburgh
	Deputy Chief	Willard K. Duckworth
	.1 Accounts and Reports	Margaret L. Spiess
	.2 Classification	Pearl E. Miller
	.3 Tabulation	John P. Lafon
	.4 Voucher Examination	Matilda Udoff
	.5 Billing and Collection	Doris J. Lothrop
	.6 Payroll	Kathryn L. Rock
41	**PERSONNEL**	George R. Porter
	Assistant Chief	Frankie R. Keyser
	.1 Board of Civil Service Examiners	Edith N. Fimple
	.2 Recruitment and Placement	Frankie R. Keyser
	.3 Classification	Charles V. Ramey
	.4 Employee Relations	Ruth B. Armsby
	.5 Operations and Procedures	Helen V. Courtney
	.6 Medical Office	Dr. Charles P. Waite
42	**ADMINISTRATIVE SERVICES**	Harry P. Dalzell
	Assistant Chief	Karl L. Hafen
	Assistant for Safety and Civil Defense	Leo W. Scott
	.1 Records and Communications	Joseph L. Shulman (Acting)
	.2 Special Services	Gird M. Tolley, Jr. (Acting)
	.3 Janitorial Services	Robert C. Howey
	.4 Guard Services	Capt. William R. Allen
	.5 Transportation Services, Garage	Charles W. Anderson
	.6 Security Officer	Harry P. Dalzell
	.7 Test Administration	Randolph K. Artz
43	**SHOPS**	Frank P. Brown
	Assistant Chief	Winfield L. Drissel
	.1 Instrument Shop No. 1	David G. Kennedy
	.2 Instrument Shop No. 2	George A. Rheinbold
	.3 Instrument Shop No. 3	George A. Rheinbold
	.4 Instrument Shop No. 4	Norman C. Pines
	.5 Instrument Shop No. 5	Robert E. Ward
	.6 Instrument Shop No. 6	Andrew J. Altman
	.7 Welding and Sheet Metal Shop	Terrell C. Freemon
	.9 Tool Crib	Lewis H. Brigham
	.10 Maintenance	Winfield L. Drissel
	.11 Glassblowing Shop	Leonardo Testa
44	**SUPPLY**	George B. Kefover
	.3 Procurement	Charles B. Kipps
	.4 Property Management	Harold G. Nicholas (Acting)
45	**MANAGEMENT PLANNING STAFF**	Ivan Asay
46	**BUDGET STAFF**	Wilbur W. Bolton, Jr.
	Deputy Budget Officer	William E. Lilly
47	**INTERNAL AUDIT**	Paul McClenon

50	**PLANT**	Charles A. Dieman
	Assistant Chief	Clarence B. Crane
	.1 Power Plant	Arthur C. Ramm
	.2 Electric Shop	George V. Hall
	.3 Piping Shop	Raymond A. Watson
	.4 Construction Shop	John A. King
	.5 Paint Shop	Howell C. Walker
	.6 Labor Services	Roy B. Powell
	.7 Metal Shop	Charles Needham
	.8 Special Laboratory Service	Donald J. Leweck (Acting)
	.9 Grounds	William R. Stevenson (Acting)
	.11 Refrigeration and Air Conditioning	James S. Powers
Boulder Laboratories*		
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	Administration	S.W.J. Welch
	.1 Washington Liaison Office	Roswell C. Peavey
	.3 Personnel	Roy W. Stockwell, Jr.
	.4 General Services	Barton F. Betts
	.5 Engineering Services	Paul S. Ballif
81	**Cryogenic Engineering***	Russell B. Scott
	.1 Cryogenic Equipment	Bascom W. Birmingham (Acting)
	.2 Cryogenic Processes	Peter C. Vander Arend (Acting)
	.3 Properties of Materials	Martin M. Reynolds (Acting)
	.4 Gas Liquefaction	Victor J. Johnson (Acting)
82	**Radio Propagation Physics***	Dr. Ralph J. Slutz
	.1 Upper Atmosphere Research	Thomas N. Gautier, Jr.
	.2 Ionospheric Research	Ross Bateman
	.3 Regular Propagation Services	Walter B. Chadwick
83	**Radio Propagation Engineering***	Kenneth A. Norton
	.4 Frequency Utilization Research	Kenneth A. Norton (Acting)
	.6 Tropospheric Propagation Research	Jack W. Herbstreit
84	**Radio Standards***	H. A. Thomas
	Assistant Chief for Research	Dr. Harold Lyons
84A	High Frequency Standards Branch	William D. George
	.1 High Frequency Electrical Standards	Myron C. Selby
	.2 Radio Broadcast Service	A. H. Moran (Acting)
	.3 HF Impedance Standard	(Vacant)
84B	Microwave Standards Branch	Dr. Harold Lyons
	.6 Extreme High-Frequency and Noise	Dr. David M. Kerns (Acting)
	.7 Microwave Frequency and Spectroscopy	George Birnbaum
	.8 Microwave Circuit Standard	Robert W. Beatty (Acting)

* Laboratories located in Boulder, Colorado.

Field Stations

2 **Optics and Metrology**

Lamp Inspector, Brookline, MA

Visual Landing Aids Field Laboratory, Arcata Airport, Arcata, Humboldt County, CA

6 **Mechanics**

NBS Master Railway Track Scale Depot, Clearing, IL

9 **Mineral Products**

9.6 Concreting Materials

Allentown, PA
Denver, CO
Kansas City, MO
San Francisco, CA
Seattle, WA

80 **Central Radio Propagation Laboratory**

Radio Propagation Field Station, Anchorage, AK
Radio Propagation Field Station, Point Barrow, AK
Radio Propagation Field Station, Bluie West-1, Greenland
Radio Propagation Field Station, Guam Island
Radio Propagation Field Station, Puunene, Maui, Territory of Hawaii
Radio Propagation Field Station, Ramey Air Force Base, Puerto Rico
Radio Propagation Field Station, Fort Gulick, Panama Canal Zone
Radio Propagation Field Station, Ft. Belvoir, VA
Cheyenne Mountain Field Station, Colorado Springs, CO
Radio Propagation Laboratory, Sterling, VA
Radio Transmitting Station, Beltsville, MD
Radio Noise Recording Station, Front Royal, VA

During 1964, Director Allen V. Astin created a new management structure based upon Institutes for basic standards, for materials research, and for applied technology.

July 1, 1964

100	**OFFICE OF THE DIRECTOR**	
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	Deputy Director	Dr. Irl C. Schoonover
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	Assistant to the Director	Clarence N. Coates
	Assistant to the Director, Automatic Data Processing	W. Howard Gammon
	Senior Research Fellow	Dr. Churchill Eisenhart
	Senior Research Fellow	Dr. Ugo Fano
	Senior Research Fellow	Dr. James R. Wait
102	OFFICE OF PUBLIC INFORMATION	A. Victor Gentilini
103	TECHNICAL ANALYSIS GROUP	(Vacant)
104	OFFICE OF PROGRAM PLANNING AND EVALUATION	
	Associate Director for Resources Planning	Dr. Shirleigh Silverman
120	**ASSOCIATE DIRECTOR FOR ADMINISTRATION**	
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	Patent Advisor	David Robbins
121	ACCOUNTING	Jacob Seidenberg
	Deputy Chief	Homer McIntyre
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	.02 Classification	Edgar H. MacArthur
	.03 Tabulation	Frederick I. Baum (Acting)
	.04 Voucher Examination	Matilda Udoff
	.05 Payroll	Kathryn L. Rock
122	ADMINISTRATIVE SERVICES	Harry P. Dalzell
	Assistant Chief	Karl L. Hafen
	.01 Records and Communications	Howard L. Sampson
	.02 Special Services	Walter J. Rabbitt
	.03 Janitorial Services	Robert C. Howey
	.04 Guard Services	Capt. William J. Kane
	.05 Transportation Services	Charles W. Anderson
	.06 Security Office	Harry P. Dalzell
123	BUDGET AND MANAGEMENT	Dr. James E. Skillington, Jr.
	.01 Budget	Eugene C. Denne
	.02 Management Analysis	John B. Tallerico
124	INTERNAL AUDIT	Harold F. Whittington

125	**Personnel**	George R. Porter
	Assistant Chief	Henry C. Bothe
	.01 Board of Civil Service Examiners	Warren J. Barker
	.02 Recruitment and Placement	Henry C. Bothe
	.03 Salary and Wage Administration	Charles V. Ramey
	.04 Employee Relations and Training	Ruth B. Armsby
	.05 Operations and Procedures	Edith C. Lewis
	.06 Medical Office	Dr. A. S. Cross
126	**Plant**	M. Bernard Goetz (Acting)
	Assistant Chief	M. Bernard Goetz
	.01 Steam-Chilled Water Generation	James S. Powers
	.02 Electric Shop	Robert W. Miller
	.03 Piping	Gerard John Finan
	.04 Construction Shop	John A. King
	.05 Gaithersburg Plant Services	Berkley E. Wigglesworth
	.06 Labor Services	Roy B. Powell
	.07 Metal Shop	Donald I. Thompson
	.08 Air Conditioning and Refrigeration	Dominick M. Giampietro
	.09 Grounds	William R. Stevenson
127	**Supply**	George B. Kefover
	Deputy Chief	Arthur L. Longwell
	.01 Storeroom	Walter C. Bonner (Acting)
	.02 General Services	Fred H. Johncox (Acting)
	.03 Procurement	Charles B. Kipps
	.04 Property Management	Harold G. Nicholas
140	**ASSOCIATE DIRECTOR FOR TECHNICAL SUPPORT**	
	Associate Director	Dr. Lauriston S. Taylor
	Scientific Assistant	W. R. Ney
	International Relations	Ladislaus L. Marton
141	**Technical Publications**	W. Reeves Tilley
	Assistant Chief	William K. Gautier
	.01 Information	Robert T. Cook (Acting)
	.02 Editorial	William K. Gautier
	.03 Publications	John E. Carpenter
	.04 Photographic Services	Warren P. Richardson
	.05 Graphic Arts	Conrad F. Peters
142	**Research Information**	Dr. Lauriston S. Taylor (Acting)
	.01 Library	Sarah Ann Jones
143	**Radiation Safety**	Dr. Lauriston S. Taylor (Acting)
	.01 Health Physics	Dr. Abraham Schwebel
144	**Professional Development**	Vacant

154	**Instrument Shops**	Frank P. Brown
	Assistant Chief	Winfield L. Drissel
	.01 Instrument Shop #1	John R. Hettenhouser
	.02 Instrument Shop #2	Walter A. Koepper
	.03 Instrument Shop #3	Charles E. Taylor
	.04 Instrument Shop #4	Philip Pfaff, Jr.
	.05 Instrument Shop #5	Philip Pfaff, Jr.
	.06 Glassblowing	Enrico Deleonibus
	.07 Welding and Sheet Metal Shop	Harold E. Brown
	.08 Optical Shop	Stanley W. Gerner
	.09 Tool Crib	Lewis H. Brigham

*160 MANAGER, BOULDER LABORATORIES

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	Consultant–Statistics	Dr. Edwin L. Crow
	Consultant–Math Group and Computation Facility	Dr. John J. Sopka
	Consultant–Mathematical Physics	H. E. Brown
*161	**Administrative, Boulder Laboratories**	Samuel W. J. Welch
	.01 Consultant– Engineering	Paul S. Ballif
	.10 Management Planning	J. Berkley
	.20 Personnel	Roy W. Stockwell
	.30 Fiscal	Herbert D. Stansell
	.40 Supply	Barton F. Betts
	.50 Office Services	Richard G. Bulgin
	.60 Plant Engineering	Edgar A. Yuzwiak
	.70 Shops	John L. Hutton

200 INSTITUTE FOR BASIC STANDARDS

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	Associate Director, Measurement Services	William A. Wildhack
201	**Office of Standard Reference Data**	Dr. Edward L. Brady
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	Chemical Kinetics	Dr. Stephen A. Rossmassler
	Information Systems	Dr. Franz L. Alt
205	**Applied Mathematics**	Dr. Edward W. Cannon
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	Consultant	Ida Rhodes
	Consultant	Dr. William J. Youden
	.01 Numerical Analysis	Dr. Morris Newman
	.02 Computation	Dr. Don I. Mittleman
	.03 Statistical Engineering	Joseph M. Cameron
	.04 Mathematical Physics	Dr. William H. Pell
	.05 Operations Research	Dr. Alan J. Goldman

211	ELECTRICITY		Dr. Chester H. Page
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	.02	Electrochemistry	Dr. Walter J. Hamer
	.03	Electrical Instruments	Francis L. Hermach
	.04	Magnetic Measurements	Irvin L. Cooter
	.05	Dielectrics	Dr. Arnold H. Scott
	.06	High Voltage	Dr. F. Ralph Kotter
	.07	Absolute Electrical Measurements	Dr. Forest K. Harris
212	METROLOGY		Alvin G. McNish
	Assistant Chief		Dr. Deane B. Judd
	.11	Photometry and Colorimetry	Louis E. Barbrow
	.12	Refractometry	Dr. Francis E. Washer
	.13	Photographic Research	Calvin S. McCamy
	.21	Length	Theodore R. Young
	.22	Engineering Metrology	Irvin H. Fullmer
	.31	Mass and Volume	Paul E. Pontius
213	MECHANICS		Bruce L. Wilson
	Consultant		Dr. John M. Frankland
	Consultant		Edward C. Lloyd
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	.02	Pressure and Vacuum	Dr. Daniel P. Johnson
	.03	Fluid Mechanics	Dr. Galen B. Schubauer
	.04	Engineering Mechanics	Lafayette K. Irwin
	.05	Rheology	Dr. Robert S. Marvin
	.06	Combustion Controls	Frank R. Caldwell
221	HEAT		Dr. Ralph P. Hudson
	Assistant Chief, Thermodynamics		Dr. Charles W. Beckett
	.01	Temperature Physics	James F. Swindells
	.02	Heat Measurements	Dr. Defoe C. Ginnings
	.03	Cryogenic Physics	Dr. Ernest Ambler
	.04	Equation of State	Joseph Hilsenrath
	.05	Statistical Physics	Dr. Melville S. Green
222	ATOMIC PHYSICS		Dr. Karl G. Kessler
	.01	Spectroscopy	Dr. William C. Martin, Jr.
	.02	Infrared and Microwave Spectroscopy	Dr. David R. Lide, Jr.
	.03	Far Ultraviolet Physics	Dr. Robert P. Madden
	.04	Solid State Physics	Dr. Hans P. R. Frederikse
	.05	Electron Physics	Dr. John A. Simpson
	.06	Atomic Physics	Dr. Harold S. Boyne
	.07	Plasma Spectroscopy	Dr. Wolfgang L. Wiese
223	PHYSICAL CHEMISTRY		Dr. Merrill B. Wallenstein
	Consultant		Dr. William L. Clinton
	Consultant		Edward J. Prosen
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	.02	Theoretical Chemistry	Dr. Morris Krauss
	.11	Thermochemistry	Donald D. Wagman
	.21	Surface Chemistry	Dr. Ralph Klein
	.31	Organic Chemistry	Dr. Horace S. Isbell
	.41	Molecular Spectroscopy	Dr. David E. Mann
	.51	Elementary Processes	Dr. Robert E. Ferguson
	.52	Mass Spectrometry	Dr. Harry M. Rosenstock
	.53	Photo Chemistry and Radiation Chemistry	Dr. James R. McNesby

*224	LABORATORY ASTROPHYSICS	Dr. Lewis M. Branscomb
231	RADIATION PHYSICS	Dr. Herman W. Koch
	.01 Radiation Theory	Dr. Haakon A. Olsen
	RADIOLOGICAL PHYSICS BRANCH	Dr. J. W. Motz
	.11 X-ray Physics	Dr. J. W. Motz
	.12 Dosimetry	Dr. Scott W. Smith
	.13 X-ray Standards	Dr. Harold O. Wyckoff
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	.21 Radioactivity	Dr. Wilfrid B. Mann
	.22 Neutron Physics	Dr. Randall S. Caswell
	.23 Photonuclear Physics	Dr. Everett G. Fuller
	.24 Nuclear Spectroscopy	Dr. Raymond W. Hayward
	Accelerator Branch	Dr. James E. Leiss
	.31 Accelerator Engineering	Dr. James E. Leiss
	.32 Radiation Physics Instrumentation	Louis Costrell
	.33 Accelerator Physics	Dr. James E. Leiss
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*251	RADIO STANDARDS PHYSICS	Dr. L. Yardley Beers
	Assistant Chief	Dr. George E. Hudson
	Consultant	Dr. Paul F. Wacker
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	.02 Frequency-Time Broadcast Services	David H. Andrews
	.03 Radio and Microwave Materials	John L. Dalke
	.04 Atomic Frequency and Time Interval Standards	Dr. Richard C. Mockler
	.06 Radio Plasma	Dr. Karl B. Persson
	.07 Microwave Physics	Dr. Robert W. Zimmerer (Acting)
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	Consultant	Myron C. Selby
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	.21 HF Calibration Services	Dr. K. R. Wendt
	.22 HF Electrical Standards	Charles M. Allred
	.23 HF Impedance Standards	Robert C. Powell
	.31 Microwave Calibration Services	Roy E. Larson
	.32 Microwave Circuit Standards	Dr. Maurice B. Hall
300	INSTITUTE FOR MATERIALS RESEARCH	
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	Deputy Director	Dr. Harry C. Allen Jr. (Acting)
302	OFFICE OF STANDARD REFERENCE MATERIALS	Dr. W. Wayne Meinke

310	ANALYTICAL CHEMISTRY	Dr. W. Wayne Meinke
	Assistant Chief	Dr. Roger G. Bates
.01	Radiochemical Analysis	Dr. James R. DeVoe
.02	Spectrochemical Analysis	Bourdon F. Scribner
.03	Electrochemical Analysis	Dr. Roger G. Bates
.04	Quantitative Separations	Rolf A. Paulson (Acting)
.05	Analysis and Purification	Dr. John K. Taylor
311	POLYMERS	Dr. John D. Hoffman
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	Consultant on Polymers	Dr. Samuel G. Weissberg
	Consultant on Rubber	Dr. Lawrence A. Wood
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.02	Polymer Chemistry	Dr. Leo A. Wall
.03	Polymer Physics	Dr. Elio Passaglia
.04	Polymer Characterization	Dr. Norman P. Bekkedahl
.05	Dental Research	William T. Sweeney
.10	**Federal Standards and Specification Laboratory**	Dr. Robert B. Hobbs (Acting)
	Consultant on Leather	Dr. Joseph R. Kanagy
	Consultant on Mathematical Statistics	John Mandel
	Consultant on Paper	Jack L. Harvey (Acting)
	Consultant on Textiles	Dr. Herbert F. Schiefer
.11	Product Evaluation and Testing	Vacant
.12	Procurement Systems	Vacant
.13	Evaluation Criteria	Dr. Robert D. Stiehler
.14	Performance Research	Vacant
312	METALLURGY	Dr. Lawrence M. Kushner
	Assistant Chief	George A. Ellinger
	Consultant	Leroy L. Wyman
.01	Engineering Metallurgy	Samuel J. Rosenberg
.02	Alloy Physics	Dr. Lawrence H. Bennett
.03	Lattice Defects and Microstructures	Dr. A. William Ruff, Jr.
.04	Corrosion	George A. Ellinger
.05	Metal Physics	Dr. Robert E. Howard
.06	Electrolysis and Metal Deposition	Dr. Abner Brenner
.07	Crystallization of Metals	Dr. Robert L. Parker
313	INORGANIC MATERIALS	Dr. Harry C. Allen, Jr.
	Consultant	Dr. Gilbert Gordon
	Consultant	Dr. Ellis R. Lippincott
.01	Inorganic Chemistry	Dr. Thomas D. Coyle
.02	Glass	Clarence H. Hahner
.03	High Temperature Chemistry	Vacant
.04	Crystal Chemistry	H. Steffen Peiser
.05	Physical Properties	Dr. John B. Wachtman, Jr.
.06	Crystallography	Howard F. McMurdie
314	REACTOR RADIATIONS	Dr. Carl O. Muehlhause

*315	**CRYOGENICS**	Bascom W. Birmingham
	Assistant Chief	Dr. R. Joseph Corruccini
	Consultant	Alan F. Schmidt
	.01 Cryogenic Technical Services	William A. Wilson
	.02 Cryogenic Data Center	Victor J. Johnson
	.03 Cryogenic Properties of Solids	Dr. Richard H. Kropschot
	.04 Properties of Cryogenic Fluids	Dr. R. Joseph Corruccini
	.05 Cryogenic Systems	Dudley B. Chelton
	.06 Cryogenic Metrology	Dr. Thomas M. Flynn
	.07 Cryogenic Fluid Transport Processes	Raymond V. Smith
400	**INSTITUTE FOR APPLIED TECHNOLOGY**	
	Director	Dr. Donald A. Schon
	Deputy Director	John P. Eberhard
	Consultant	Joseph L. Swedock
	Assistant to the Director, International Standards	Dr. Archibald T. McPherson
	.01 Pilot Projects and Programs	Vacant
	.02 Invention and Innovation	Daniel V. DeSimone
	.03 Domestic Technology Information	Eric A. Tietz
	.04 AID Technology Information	Vacant
402	**OFFICE OF TECHNICAL SERVICES**	Dr. Donald A. Schon
403	**OFFICE OF INDUSTRIAL SERVICES**	Robert L. Stern
404	**OFFICE OF WEIGHTS AND MEASURES**	Malcolm W. Jensen
405	**OFFICE OF ENGINEERING STANDARDS**	Vacant
	Commodity Standards	Alfred S. Best
	Technical Standards Coordination	Joan Hartman
410	**TECHNICAL DOCUMENTATION CENTER**	Bernard M. Fry
	.10 Document Management Branch	Paul W. Larsen
	.20 Document Analysis and Reference Branch	Lillian A. Hamrick
	.30 Automated Systems and Services Branch	Vacant
	.40 Customer Relations Branch	James E. Wheat
	.50 Plans and Development Branch	Jeremiah F. Harrington
	.60 Administrative Services Branch	John L. Demarest
	.70 Joint Publications Research Service	Thomas W. Miller
421	**BUILDING RESEARCH**	Dr. Allan A. Bates
	.01 Structural Engineering	David Watstein
	.02 Fire Research	Dr. Alexander F. Robertson
	.03 Mechanical Systems	Paul R. Achenbach
	.04 Organic Building Materials	Dr. William W. Walton
	.05 Codes and Safety Standards	Dr. Allan A. Bates (Acting)
	.06 Heat Transfer	Henry E. Robinson
	.07 Inorganic Building Materials	Dr. Bruce E. Foster
	.08 Metallic Building Materials	Dwight G. Moore
422	**INDUSTRIAL EQUIPMENT TECHNOLOGY**	Vacant

423	**INFORMATION TECHNOLOGY**	Samuel N. Alexander
	PILOT	James P. Nigro
	.01 Components and Techniques	Robert D. Elbourn
	.02 Computer Technology	James A. Cunningham
	.03 Measurements Automation	Raymond T. Moore
	.04 Engineering Applications	James P. Nigro
	.05 Systems Analysis	Samuel N. Alexander (Acting)
424	**PERFORMANCE TEST DEVELOPMENT**	Vacant
425	**INSTRUMENTATION**	G. Franklin Montgomery
	.01 Engineering Electronics	Gustave Shapiro
	.02 Electron Devices	Charles P. Marsden
	.03 Electronic Instrumentation	G. Franklin Montgomery (Acting)
	.04 Mechanical Instruments	Arnold Wexler
	.05 Basic Instrumentation	Joshua Stern
426	**TRANSPORT SYSTEMS**	Dr. Siegfried M. Breuning
427	**TEXTILES AND APPAREL TECHNOLOGY CENTER**	Robert L. Stern (Acting)
	Consultant	Gary K. Stonebraker
	Mathematician	Jerome A. Yurow
	Industrial Specialist	Gary C. McKay
	Consultant	Robert H. Ramsey
	Consultant	Ernest R. Kaswell
	.01 Contract Research Program	Vacant
	.02 Technical Support Program	Vacant
***500**	**CENTRAL RADIO PROPAGATION LABORATORY**	
	Director	Dr. C. Gordon Little
	Deputy Director	Jack W. Herbstreit
	Senior Research Fellow	Dr. James R. Wait
	Consultant	Kenneth A. Norton
	Consultant	Roger M. Gallet
	Consultant	A. Glenn Jean, Jr.
	CRPL Liaison and Program Development	Alan H. Shapley
	Consultant Radio Wave Propagation	Dr. James R. Wait
***582**	**IONOSPHERE RESEARCH AND PROPAGATION**	Robert W. Knecht
	Assistant Chief	Thomas N. Gautier
	Consultant	Dr. Lawrence R. Megill
	Consultant	Dr. H. Herbert Howe
	.05 Ultra Low Frequency Research	Dr. Wallace H. Campbell
	.10 LF and VLF Research	Douglass D. Crombie
	.20 Ionosphere Research	Dr. Kenneth Davies
	.30 Prediction Services	Margo Leftin
	.40 Sun-Earth Relationships	Dr. Thomas E. VanZandt
	.50 Field Engineering	Harry G. Sellery
	.60 Radio Warning Services	J. Virginia Lincoln
	.70 Vertical Soundings Research	John W. Wright

*583	TROPOSPHERE AND SPACE TELECOMMUNICATIONS	Robert S. Kirby (Acting)
	Consultant	Dr. David M. Gates
	Consultant, Terminal Equipment	Edwin F. Florman
.10	Data Reduction Instrumentation	Walter E. Johnson
.40	Radio Noise	William Q. Crichlow
.50	Tropospheric Measurements	Martin T. Decker
.60	Tropospheric Analysis	Philip L. Rice
.70	Spectrum Utilization Research	Albrecht P. Barsis
.80	Radio Meteorology	Bradford R. Bean
.90	Lower Atmosphere Physics	Dr. Moody C. Thompson, Jr.
*585	RADIO SYSTEMS	Richard C. Kirby
	Assistant Chief	Donald W. Patterson
	Assistant Chief	William F. Utlaut
	Consultant	George W. Haydon
.10	Applied Electromagnetic Theory	J. Ralph Johler
.20	HF and VHF Research	Lowell H. Tveten
.30	Frequency Utilization	George W. Haydon
.40	Modulation Research	Clark C. Watterson
.50	Antenna Research	Herman V. Cottony
.60	Radiodetermination	Gifford Hefley
*587	UPPER ATMOSPHERE AND SPACE PHYSICS	Dr. Ernest K. Smith, Jr.
	Assistant Chief	Dr. Floyd L. Taylor
	Consultant	Dana K. Bailey
	Consultant	Dr. George C. Reid
	Consultant	Dr. Ralph J. Slutz
.10	Upper Atmosphere and Plasma Physics	Vacant
.20	High Latitude Ionospheric Physics	Dr. Hugh J. A. Chivers
.30	Atmospheric Collision Processes	Dr. Eldon E. Ferguson
.50	Ionosphere and Exosphere Scatter	Dr. Kenneth L. Bowles
.70	Airglow and Aurora	Dr. Franklin E. Roach
.80	Ionospheric Radio Astronomy	Robert S. Lawrence

*Laboratories located in Boulder, Colorado.

FIELD STATIONS

212 METROLOGY

Visual Aids Field Laboratory, Arcata, CA
Master Railway Track Scale Depot, Clearing, IL

410.70 TECHNICAL DOCUMENTATION CENTER, JOINT PUBLICATIONS RESEARCH SERVICE

San Francisco, CA
New York, NY

421.07 BUILDING RESEARCH, INORGANIC BUILDING MATERIALS

San Francisco, CA
Denver, CO
Seattle, WA

500 **CENTRAL RADIO PROPAGATION LABORATORY**

Radio Propagation Field Station, Anchorage, AK
Radio Propagation Field Station, Barrow, AK
Ionosonde and Conjugate Points Station, Byrd Station, Antarctica
Radio Noise Station, USNS ElTanin, Antarctica
Conjugate Points Station, Charlevoix, Quebec
Western Test Range, Lompoc (Point Arguello), CA
Radio Propagation Field Station, Akron, CO
Boulder Magnetic Observatory, Boulder, CO
Cheyenne Mountain Radio Propagation Station, Colorado Springs, CO
HF/VHF Research Section Radio Propagation Transmissions Site, Erie, CO
Standard Frequency Stations WWVB/WWVL, For Collins, CO
Antenna Research Test Site, Green Mountain Mesa, CO
Radio Meteorological Field Site, Radio Noise Station and Telemetry Recording Station, Gun Barrel Hill, CO
Radio Propagation Field Station, Haswell, CO
Ionosphere Research Field Station, Kolb, CO
VLF/ELF Propagation Station, Lafayette, CO
Fritz Peak Observatory, Aurora and Airglow Station, Rollinsville, CO
Radio Propagation Research Station, Table Mesa, CO
Radio Noise Recording Station, Koloa, Kauai, HA
Radio Propagation and Standard Frequency Station WWVH, Puunene, Maui, HA
Radio Propagation Transmissions Station, Havana, IL
Standard Frequency Station WWV, Greenbelt, MD
Radio Noise Recording Station, Warrensburg, MO
Radio Propagation Field Station, Mangum, OK
Jicamarca Radar Observatory, Lima, Peru
Radio Propagation Field Station, Ft. Belvoir, VA
Radio Noise Station, Front Royal, VA
Ionosphere Sounding Station, Wallops Island, VA
Bill Radio Noise Recording Station, Douglas, WY

The July, 1978 organizational chart reflects Director Ernest Ambler's creation of a laboratory structure.

July 1, 1978

<u>100 Office of the Director</u>

Director	Dr. Ernest Ambler
Deputy Director	Dr. Thomas A. Dillon
Legal Advisor	Allen J. Farrar
Congressional Affairs Officer	Esther C. Cassidy
Equal Employment Opportunity Coordinator	Dwight F. Doxey, Acting
Technology Advisor	Dr. Howard E. Sorrows
Visiting Committee/Evaluation Panels	Kay J. Byerly
Presentations	Donald V. Baker
Industrial Liaison	Peter R. DeBruyn
State and Local Governments	James M. Wyckoff
Associate Director for International Affairs	Dr. Edward L. Brady
Office of International Relations	H. Steffen Peiser

110 Associate Director for Programs, Budget, and Finance

Associate Director	Raymond G. Kammer

111 Program Office

Chief	Raymond G. Kammer
Program Analyst	Dr. Harvey Yakowitz
Analyst, NML	Dr. Peter L. Heydemann
	Dr. Gregory J. Rosasco
Analyst, NEL	Dr. Richard D. Marshall
	Judith F. Gilsinn
Analyst, ICST	Dr. Seldon L. Stewart
Analyst, DAIS	Stephen L. Damours

112 Budget Office

Chief	Thomas A. Gary
Senior Analyst—Budget Formulation	Joseph E. Fones
Senior Analyst—Budget Justification	Janet B. Miller

113 Office of the Comptroller

Comptroller	Larry D. Stout
Deputy Comptroller	David B. Shreve
Special Projects	Edgar H. MacArthur
General Accounting	John C. McGuffin
Operations	Henry L. Kenno
Accounts Payable	Eleanor W. Filban

114 Planning Office

Chief	Raymond G. Kammer, Acting

320 Director of Administrative and Information Systems

Director	Richard P. Bartlett, Jr.
Program Coordinator	Joseph C. Aubele

321 Public Information Division

Chief	Richard S. Franzen
Audio/Visual Information	Ronald E. Meininger
Media Liaison	Madeleine S. Jacobs
Special Activities	Sara R. Torrence

322 Personnel Division

Chief	Mati Tammaru
Deputy	Sharon April
Labor/Management Relations	John L. O'Neill
Personnel Operations/Boulder	James H. Spencer
Employee Development	John C. Collins
Classification	Walter R. Scheltema
Operations and Procedures	Marlene O. Posey

323	**Management and Organization Division**	
	Chief	Roger A. Dixon
	Consultive Services	Wayne B. Davis
	Directives Management	Sharon B. Weeks
	Organization Design	Marguerite R. Hubanks
	Management Systems	Roger A. Dixon
340	**Center for Information Systems**	
	Chief	John T. Hall
341	**Computing Systems Design Division**	
	Chief	Eugene I. Grunby
	Advanced Systems	Edward J. Barkmeyer
	Administrative Systems Design	Robert E. Stant
	Administrative Systems Applications	Lucille E. Sithens
342	**Library Division**	
	Chief	Patricia W. Berger
	Information Services	K. J. Patrias
	Resources Development	Marvin A. Bond
343	**Office Management Division**	
	Chief	Richard de la Menardiere, Acting
	Office Support Coordinator	Frances V. Gary
	DoC Procurement Liaison	R. Keith Chandler
	Procurement	Virgella Randolph
	Forms Management	G. Fenney
	Records Management	Philip V. Proulx
	Conference Facilities	Omar K. Halmat
	Printing and Duplicating	Aaron J. Lucas
	Visual Arts	James V. Schick
344	**Technical Information and Publications Division**	
	Chief	W. Reeves Tilley
	Executive Secretary, WERB	Dr. Robert F. Blunt
	Inquiry Service	Norma E. Redstone
	Publication Production	John J. Rochford
	Electronic Typesetting	Rebecca J. Morehouse
345	**Computer Services Division**	
	Chief	Martin R. Shaver
	Deputy	Leroy M. Allison
	Customer Support	Ralph A. Palladino
	Operations	Andrew Selepak
	Technical Services	George A. Dines
	Systems Software	John A. Coffey
	Hardware Maintenance	Donald C. Jensen
350	**Center for Facilities Management**	
	Director	Karl E. Bell
	Program Coordinator	Iris M. Lloyd

351	**Plant Division**	
	Chief	John N. Brewer, Jr.
	Deputy	Edmund H. Keranen
	Special Projects	DeForest Z. Rathbone, Jr.
	Contract Administration	Julius C. Chieppa
	Industrial Planning	G. D. Scullen
	Maintenance Engineering	Anthony A. White
	Design Engineering	T. B. McKneely
	Apprentice Programs	Robert W. Miller
	Steam & Chilled Water Generation	Leslie E. Wachter
	Electric Shop	Robert W. Miller
	Piping Shop	Kenneth L. Lowe
	Construction Shop	David W. Hughes
	Paint Shop	James M. Marlett, Sr.
	Sheet Metal Shop	Donald I. Thompson
	Air Conditioning and Refrigeration	Dominick M. Giampietro
	Grounds	Dale C. Sullivan
352	**Instrument Shops Division**	
	Chief	David S. Bettwy
	Assistant	James N. Strohlein
	Production Control	Ralph L. Whalen, Jr.
	Engineering Design	James N. Strohlein
	Scientific Instrument Shop	Stanley W. Gerner
	Optical Shop	Edward P. Muth
	Numerically Controlled Machines	Robert E. Lach
	Specialty Shop	John R. Pidgeon
	Glass Blowing Shop	Enrico N. DeLeonibus
	Welding and Sheet Metal Shop	Harold E. Brown
353	**Facilities Services Division**	
	Chief	Walter J. Rabbitt
	Consultants Supply	John F. Kennedy
		Walter C. Bonner, Jr.
	Fire Protection Services	Chief Charles O. Baker
	Janitorial Services	Henry J. Pulver, Acting
	Mail	Margie E. Kaszuba
	Materiel Support	Charles W. Castle
	Physical Security	Capt. Frank Langston
	Property and Stores	Mary L. Davison
	SRM Support	George R. Fairchild
	Telecommunications	Larry J. Loveland
	Traffic Manager	Robert J. Lewis
	Transportation Services	Harvey E. McCoy
354	**Occupational Health and Safety Division**	
	Chief	Lyman E. Pevey, Acting
	Safety	Lyman E. Pevey
	Health Physics	Dr. Abraham Schwebel
	Medical Office	Dr. George Sharpe
	Workers' Compensation	Janet C. Wilt

360	**Boulder Executive Office**	
	Executive Officer	Arthur R. Hauler
	Financial Systems	Thomas M. Rizzi
	Staff Services	Rudolf F. Meyers
	Safety	Winston W. Scott, Jr.
	Personnel Security	Ann B. Hamilton
	Communications	Alden E. Clifford, III
	Physical Security	William W. Fabing
	Program Information	Ralph F. Desch
	Visual Information	Darwin B. Miner
361	**Boulder Supply Services Division**	
	Chief	Johannes S. Roettenbacher
	Deputy	Merle V. Gibson
	Property Records	Carl B. Diechman
	Property Utilization	William Kellett
	Shipping and Receiving	O. Russell Dallman
	Mail	Ted C. Fahrenholtz
	Stores	Robert C. Damiana
	Travel	Dolly A. Quate
362	**Boulder Instrument Shops Division**	
	Chief	William A. Wilson
	Production Control	Kenneth L. Nuss
	Mechanical Design	Victor Lecinski
	Measurements	Lloyd M. Kneebone
	Glass Shop	Jerry G. Shepherd
	Scientific Instruments	Philip F. Biddle
	Apprentice Program	Michael P. Cawley
	Tool Crib	Ernest L. Rooks
	Numerical Machines	Herbert H. Garing
	Welding, Sheet Metal, Plating	William F. Decker
363	**Boulder Plant Division**	
	Chief	Vacant
	Training Administration	Gordon W. DeKrey
	Plant Engineer	Gary W. Johnson
	Operations Manager	Kenneth B. Martin
	Building Maintenance	Donald D. Rice
	Roads and Grounds	Wilmer L. Schweikert
	Custodial	Leslie C. Chance
410	**Director, NBS/Boulder Laboratories**	
	Chief	Bascom W. Birmingham
	Program Coordination	Robert D. Harrington

500	**National Measurement Laboratory**	
	Director	Dr. John D. Hoffman
	Deputy Director for Resources and Operations	Dr. Emanuel Horowitz
	Associate Director for Long-Range Planning	Dr. David T. Goldman (Acting)
	Deputy Director for Programs	Dr. Donald R. Johnson
	Executive Officer	Ronald B. Johnson
	Administrative Officer	Robert F. Martin
	Senior Science Advisor	Dr. Hans J. Oser
	Scientific Assistants	Dr. Ian R. Bartky
		Dr. Wayne A. Cassatt
		Dr. Lucy B. Hagan
		Dr. Ruth A. Haines
		Lottie T. McClendon
		Dr. Gilbert M. Ugiansky
	Statistical Consultant	Dr. John Mandel
501	**Office of Nondestructive Evaluation**	
	Chief	Harry Berger
502	**Office of Environmental Measurements**	
	Chief	Dr. Cary Gravatt (Acting)
	Air Programs	Vacant
	Water Programs	Dr. Bruce W. Morrissey
503	**Office of Standard Reference Materials**	
	Chief	J. Paul Cali
	Deputy	George A. Uriano
	Chief Standards Coordinator	Robert E. Michaelis
	Standards Coordinators	Robert Alvarez
		R. Keith Kirby
		William P. Reed
	Technical Representative	Richard W. Seward
	Marketing	Ruth H. Meyer
504	**Office of Standard Reference Data**	
	Chief	Dr. David R. Lide, Jr.
	Technical Liaison	Dr. Sherman P. Fivozinsky
	Data Systems Design	Dr. David R. Lide, Jr.
	Energy and Environmental	Dr. Lewis H. Gevantman
	Industrial Processes	Dr. Howard J. White, Jr.
	Materials Utilization	Dr. Steven A. Rossmassler
	Physical Sciences Data	Dr. David R. Lide, Jr.
505	**Office of Measurements for Nuclear Safeguards**	
	Chief	Dr. H. Thomas Yolken
506	**Office of Recycled Materials**	
	Chief	Dr. Donald R. Johnson, Acting
510	**Associate Director for Measurement Services, NML**	
	Associate Director	Dr. Arthur O. McCoubrey, Acting

511	**Office of Weights and Measures**	
	Chief	Albert D. Tholen, Acting
512	**Office of Measurement Services**	
	Chief	Dr. Brian C. Belanger
513	**Office of Domestic and International Measurement Standards**	
	Chief	David E. Edgerly
520	**Center for Absolute Physical Quantities**	
	Director	Dr. Karl G. Kessler
	Deputy Director	Dr. Ralph P. Hudson
	Assistant to the Director	Dr. W. Gary Schweitzer, Jr.
	Quantum Metrology Group Leader, Senior Research Fellow	Dr. Richard D. Deslattes
521	**Electrical Measurements and Standards Division**	
	Chief	Dr. Barry N. Taylor
522	**Temperature Measurements and Standards Division**	
	Chief	Dr. James F. Schooley
523	**Length and Mass Measurements and Standards Division**	
	Chief	Dr. Ralph P. Hudson, Acting
524	**Time and Frequency Division, Boulder**	
	Chief	Dr. James A. Barnes
525	**Quantum Physics Division, Boulder**	
	Chief	Dr. Gordon H. Dunn
530	**Center for Radiation Research**	
	Director	Dr. James E. Leiss
	Deputy	Dr. James A. O'Connell, Acting
	Assistant to the Director	James A. Hormuth
	Radiation Measurements	Elmer H. Eisenhower
531	**Atomic and Plasma Radiation Division**	
	Chief	Dr. Wolfgang L. Wiese, Acting
532	**Nuclear Radiation Division**	
	Chief	Dr. Randall S. Caswell, Acting
533	**Radiation Physics Division**	
	Chief	Dr. Christopher E. Kuyatt
534	**Radiometric Physics Division**	
	Chief	Dr. Jack L. Tech
535	**Radiation Source and Instrumentation Division**	
	Chief	Dr. Samuel Penner, Acting

540	**Center for Thermodynamics and Molecular Science**	
	Director	Dr. Milton D. Scheer
	Deputy Director	Dr. William H. Kirchhoff
541	**Surface Science Division**	
	Chief	Dr. Cedric J. Powell
542	**Chemical Kinetics Division**	
	Chief	Dr. Wing Tsang
543	**Chemical Thermodynamics Division**	
	Chief	Dr. David Garvin
544	**Thermophysics Division**	
	Chief	Dr. Harold J. Raveche
545	**Molecular Spectroscopy Division**	
	Chief	Dr. Merrill M. Hessel
550	**Center for Analytical Chemistry**	
	Director	Dr. Philip D. LaFleur
	Deputy	Dr. Curt W. Reimann
	Scientific Assistant to the Director	Dr. Richard A. Durst
	Service Analysis Coordinator	Dr. Robert W. Burke
	Instrument Development Group	Dr. James R. DeVoe
551	**Inorganic Analytical Research Division**	
	Chief	Dr. I. Lynus Barnes
552	**Organic Analytical Research Division**	
	Chief	Dr. Harry S. Hertz
553	**Gas and Particulate Science Division**	
	Chief	Dr. John K. Taylor
560	**Center for Materials Science**	
	Director	Dr. John B. Wachtman, Jr.
	Deputy Director	Dr. Elio Passaglia, Acting
	Assistant for Planning	Dr. Bruce W. Steiner
	Assistant for Other Agency Programs	Samuel J. Schneider
	Center Scientists	Dr. John W. Cahn
		Dr. Robb M. Thomson
	Signal Processing and Imaging	Dr. Melvin Linzer
	Fibrous Systems	Donald G. Fletcher
561	**Chemical Stability and Corrosion Division**	
	Chief	Dr. Thomas D. Coyle
562	**Fracture and Deformation Division**	
	Chief	Dr. Sheldon M. Wiederhorn

563	**Polymer Science and Standards Divison**	
	Chief	Dr. Ronald K. Eby
564	**Metal Science and Standards Division**	
	Chief	Dr. A. William Ruff, Jr., Acting
565	**Ceramics, Glass, and Solid State Science Division**	
	Chief	Dr. Hans P.R. Frederikse
566	**Reactor Radiation Division**	
	Chief	Dr. Robert S. Carter
600	**Institute for Computer Sciences and Technology**	
	Director	M. Zane Thornton, Acting
	Deputy Director	M. Zane Thornton
	Associate Director for Telecommunications	Edwin J. Istvan
	Senior Scientist for Computer Science	Dr. Joseph O. Harrison, Jr.
	Assistant for Computer Utilization	Robert P. Blanc
	Assistant for Technical Communications	Grace G. Burns
	Manager, Pattern Recognition Program	Joseph H. Wegstein
	Executive Officer	Ben C. Tate, Jr.
	Automatic Data Processing Standards	Harry S. White
		Madeleine M. Henderson
640	**Systems and Software Division**	
	Chief	Seymour Jeffrey
	Systems Architecture	Dr. Thomas C. Lowe
	Computer Science	Dr. Dennis W. Fife
	Applied Automatic Data Processing Technology	John F. Wood
650	**Computer Systems Engineering Division**	
	Chief	Thomas N. Pyke, Jr.
	Computer Systems	Raymond T. Moore
	Computer Networking	Dr. Stephen R. Kimbleton
	Data Acquisition and Storage	George E. Clark
660	**Information Technology Division**	
	Chief	M. Zane Thornton, Acting
700	**National Engineering Laboratory**	
	Director	Dr. John W. Lyons
	Deputy Director	Dr. James R. Wright
	Associate Director for Programs	Samuel Kramer, Acting
	Associate Director for Planning	Vacant
	Associate Director for Technical Evaluation	Dr. George A. Sinnott, Acting
	Executive Officer	D. Michael Stogsdill
	Administrative Officer	John M. Smith
710	**Center for Applied Mathematics**	
	Director	Dr. Burton H. Colvin
	Deputy	Dr. Joan R. Rosenblatt, Acting

711	**Mathematical Analysis Division**	
	Chief	Dr. Frederick C. Johnson, Acting
712	**Operations Research Division**	
	Chief	Dr. Alan J. Goldman
713	**Scientific Computing Division**	
	Chief	Dr. Burton H. Colvin, Acting
714	**Statistical Engineering Division**	
	Chief	Dr. Harry H. Ku, Acting
720	**Center for Electronics and Electrical Engineering**	
	Director	Judson C. French
	Deputy	Director Dr. Alvin H. Sher
721	**Electron Devices Division**	
	Chief	Dr. W. Murray Bullis
722	**Electrosystems Division**	
	Chief	Dr. Oskars Petersons, Acting
723	**Electromagnetic Fields Division, Boulder**	
	Chief	Dr. Harold S. Boyne
724	**Electromagnetic Technology Division, Boulder**	
	Chief	Dr. Robert A. Kamper, Acting
730	**Center for Mechanical Engineering and Process Technology**	
	Director	Dr. John A. Simpson
	Deputy Director	Dr. John M. Evans
731	**Mechanical Processes Division**	
	Chief	Dr. Russell D. Young, Acting
732	**Fluid Engineering Division**	
	Chief	Dr. George E. Mattingly
733	**Thermal Processes Division**	
	Chief	Dr. Kenneth G. Kreider, Acting
734	**Industrial Engineering Division**	
	Chief	Vacant
735	**Acoustical Engineering Division**	
	Chief	Dr. David S. Pallett
736	**hermophysical Properties Division, Boulder**	
	Chief	Dr. Richard H. Kropschot
740	**Center for Building Technology**	
	Director	Dr. Richard N. Wright
	Deputy	Director Harry E. Thompson
741	**Structures and Materials Division**	
	Chief	Dr. Edward O. Pfrang
742	**Building Thermal and Service Systems Division**	
	Chief	Dr. Preston E. McNall

743	**Environmental Design Research Division**	
	Chief	Dr. Francis T. Ventre
744	**Building Economics and Regulatory Technology Division**	
	Chief	James G. Gross, Acting
750	**Center for Fire Research**	
	Director	Dr. Frederic B. Clarke, III, Acting
	Deputy Director	Dr. Frederic B. Clarke, III
751	**Fire Science Division**	
	Chief	Dr. Robert S. Levine
752	**Fire Safety Engineering Division**	
	Chief	Irwin A. Benjamin
760	**Center for Consumer Product Technology**	
	Director	Dr. Stanley I. Warshaw
	Deputy Director	John L. Donaldson, Acting
761	**Consumer Sciences Division**	
	Chief	Dr. Harold P. Van Cott
762	**Product Performance Engineering Division**	
	Chief	Dr. Andrew J. Fowell
763	**Product Safety Technology Division**	
	Chief	Walter G. Leight
770	**Center for Field Methods**	
	Director	Richard T. Penn, Acting
780	**Office of Engineering Standards**	
	Director	Gene A. Rowland
	Deputy	William C. Cullen
781	**Office of Standards Development**	
	Chief	Dr. Lawrence D. Eicher
782	**Office of Testing Laboratory Technology**	
	Chief	Dr. Norman F. Somes
783	**Office of International Engineering Standards**	
	Chief	William E. Andrus, Jr.
790	**Office of Energy Programs**	
	Director	Dr. Jack E. Snell
791	**Office of Energy-Related Inventions**	
	Chief	George P. Lewett

The organizational chart for March 1991 showed the structure established by Director John W. Lyons in response to the legislation that changed the National Bureau of Standards into the National Institute for Standards and Technology.

March, 1991

100	**Office of the Director**	
	Director	Dr. John W. Lyons
	Deputy Director	Raymond G. Kammer
	Associate Director	Samuel Kramer
	Counselor to the Director	M. G. Stanley
	Congressional and Legislative Affairs	Esther C. Cassidy
102	**Office of Quality Programs**	
	Director	Dr. Curt W. Reimann
104	**Office of the Director, Boulder Laboratories**	
	Director	Dr. Robert A. Kamper
106	**Program Office**	
	Director	Elaine Bunten-Mines
	Senior Analyst	Vacant
	Senior Economist	Dr. Gregory C. Tassey
	Analyst MSEL/BFRL	Dr. David C. Cranmer
	Analyst CSL/CAML/TS	Richard J. Linn, Jr.
	Analyst EEEL/MEL	Allen C. Newell
	Analyst CSTL/PL	Robert L. Watters, Jr.
107	**Budget Office**	
	Director	Thomas A. Gary
	Justification and Analysis	Joann L. Beck
	Formulation and Financial Management Systems	Donald E. Drinkwater
108	**Office of Personnel and Civil Rights**	
	Personnel Officer	Elizabeth W. Stroud
	Demonstration Project	Allen F. Cassady
	Staff Services	H. James Reese
	Operations	Ellen M. Dowd
	Civil Rights	Alvin C. Lewis
109	**Director for International and Academic Affairs**	
	Director	Dr. George A. Sinnott
	Deputy Director for International Affairs	Dr. Kenneth F. Gordon
	Deputy Director for Academic Affairs	Dr. Burton H. Colvin
	Director, Office of International Relations	Dr. B. Stephen Carpenter
150	**Advanced Technology Program**	
	Director	George A. Uriano
	Deputy Director	Dr. Brian C. Belanger
200	**Office of the Director of Technology Services**	
	Director	Dr. Donald R. Johnson
	Deputy Director	David E. Edgerly
201	**Manufacturing Technology Centers Program**	
	Director	Dr. Philip N. Nanzetta, Acting

210	**Office of Standards Services**	
	Director	Dr. Stanley I. Warshaw
	Deputy Director	Walter G. Leight
211	**Standards Code and Information Program**	
	Chief	John L. Donaldson
212	**Standards Management Program**	
	Chief	Dr. Samuel E. Chappell
213	**Weights and Measures Program**	
	Chief	Albert D. Tholen
	Laws, Regulations, and Commodities	Dr. Carol S. Brickenkamp
	Device Technology	Henry V. Oppermann
220	**Office of Technology Commercialization**	
	Director	Dr. Cary Gravatt
221	**Research and Technology Applications Program**	
	Chief	Joseph G. Berke
222	**Technology Development and Small Business Program**	
	Chief	B. E. Mattson
230	**Office of Measurement Services**	
	Director	Stanley D. Rasberry
231	**Standard Reference Data Program**	
	Chief	Dr. Malcolm W. Chase
	Data Systems Development	Phoebe Fagan
232	**Standard Reference Materials Program**	
	Chief	Stanley D. Rasberry, Acting
	Production and Certification	Thomas E. Gills
233	**Physical Measurement Services Program**	
	Chief	Dr. Joseph D. Simmons
234	**Laboratory Accreditation Program**	
	Chief	Nancy M. Trahey
240	**Office of Technology Evaluation and Assessment**	
	Director	George P. Lewett
	Deputy Director	Dr. Jaromir J. Ulbrecht
241	**Energy-Related Inventions Program**	
	Chief	George P. Lewett, Acting

242	**Non-Energy-Related Inventions Program**	
	Chief	George P. Lewett, Acting
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