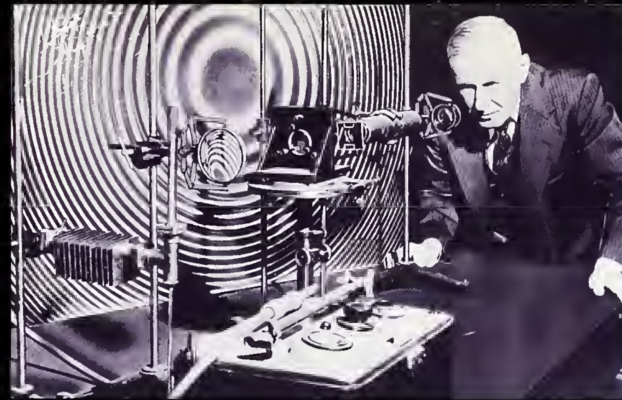


NIST at 100

Foundations for Progress

NIST
National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce

1901·2001
NIST CENTENNIAL

From NBS to NIST

Over the past century, the National Institute of Standards and Technology has had several different names. Founded as the National Bureau of Standards in 1901, it was renamed Bureau of Standards in 1903. In 1934, the word "national" was affixed again to its name. For more than 50 years it remained the National Bureau of Standards, or NBS. It became the National Institute of Standards and Technology, or NIST, in 1988. To eliminate confusion, the name National Institute of Standards and Technology is used throughout this brochure.

During its first 100 years, NIST was led by the following directors:

Samuel W. Stratton, 1901-1922
George K. Burgess, 1923-1932
Lyman J. Briggs, 1932-1945
Edward U. Condon, 1945-1951
Allen V. Astin, 1951-1969
Lewis M. Branscomb, 1969-1972
Richard W. Roberts, 1973-1975
Ernest Ambler, 1975-1989
John W. Lyons, 1990-1993
Arati Prabhakar, 1993-1997
Raymond G. Kammer, 1997-Present

For information on the cover photos: Front cover clockwise, from top, see p. 27, p. 49, and p. 47; back cover clockwise, from top, see p. 3, p. 53, p. 36, and p. 24.

NIST at 100

Foundations for Progress

The new millennium is opening with the Information Age shining on its horizon, just as the last century unfolded with the dawn of the Age of Electricity. Americans have experienced a 100-year span of extraordinary improvements in the U.S. economy and quality of life. Since 1901, the National Institute of Standards and Technology has contributed to these advances by building the foundations for technological progress.

NIST has been a reliable source of assistance to industry, science, and government. Its research, measurement tools, and technical services are integrated deeply into many of the systems and operations that drive the economy. Factories, communication and transportation networks, laboratories, hospitals, educational organizations, service companies, and the extended enterprises of the new economy all rely on NIST.

On the threshold of its second century, NIST is committed to partnering even more vigorously with industry, science, and government to build an advanced science and technology infrastructure—the foundations needed to ensure future progress and prosperity for U.S. industry and the nation.◆

The Founding

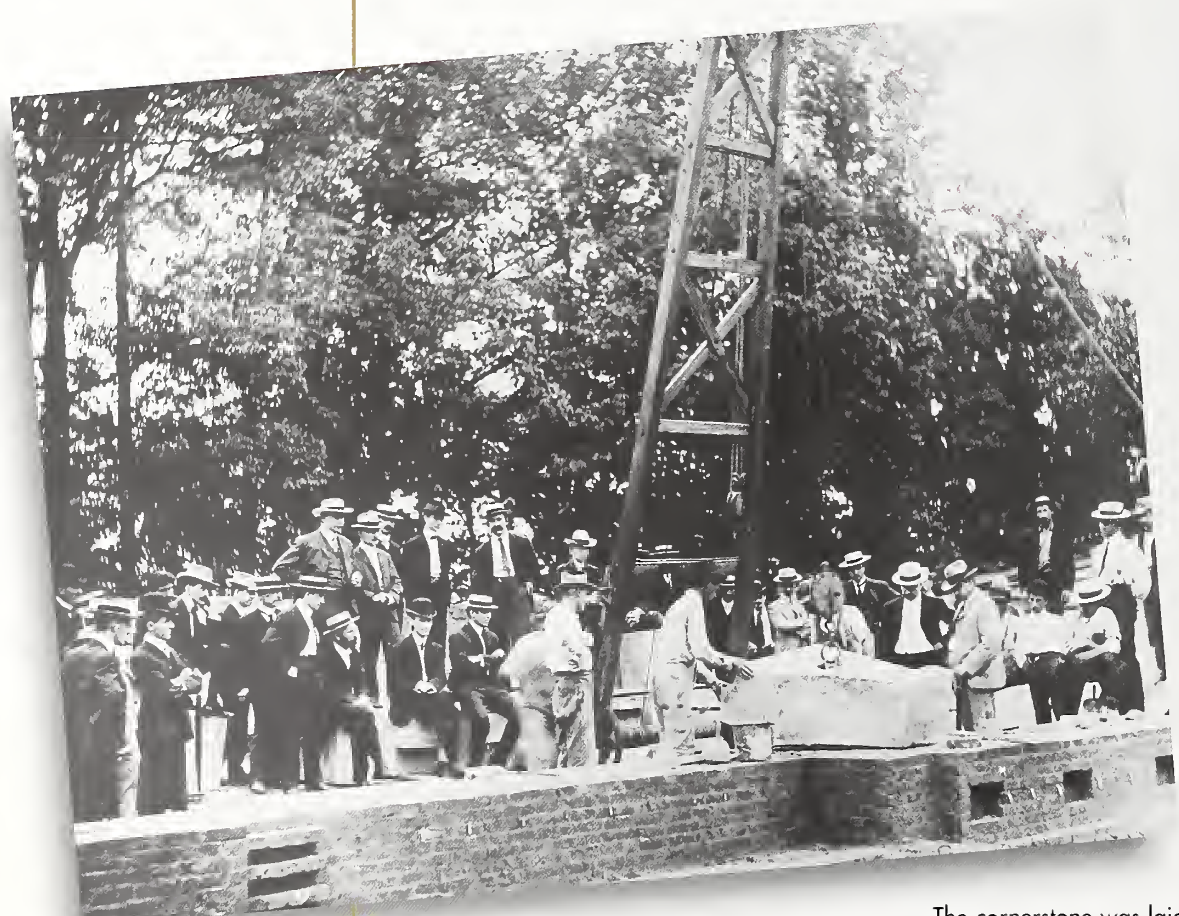
Before air conditioning, airplanes, and plastics were invented, and before science was changed forever by Albert Einstein's special theory of relativity, the National Institute of Standards and Technology (NIST) began laying the technical foundation for the world's most prosperous nation.

Chartered by the U.S. Congress on March 3, 1901, it was the first physical science research laboratory of the federal government, established at about the same time as the nation's first commercial laboratory. Teddy Roosevelt had just become President; a middle-class annual income was no more than $5,000. It was the dawn of the age of technology.

At that time, the United States had few, if any, authoritative national standards for any quantities or products. What it had was a patchwork of locally and regionally applied standards, often arbitrary, that were a source of confusion in commerce. It was difficult for Americans to conduct fair transactions or get parts to fit together properly. Construction materials were of uneven quality, and household products were unreliable. Few Americans worked as scientists, because most scientific work was based overseas.

Yet the United States was becoming a world power, with an industrial economy driven by the steam engine, the railroad, and the expanding reach of electricity. Other industrialized nations already had established standards laboratories. The need for such an organization in the United States was discussed for many years by scientists and engineers. One complained, for example, that he had to contend with eight different "authoritative" values for the U.S. gallon. The growing electrical industry needed measuring instruments and was often involved in litigation because of the lack of standards. American instruments had to be sent abroad for calibration.

The nation already had an office of weights and measures. The first efforts to provide accurate (albeit non-legal) standards of weights and measures were made in the 1830s by Ferdinand Rudolph Hassler, a Swiss engineer and metrologist who immi-



The cornerstone was laid at the original NIST site in Washington, D.C., in 1903.

Ensuring Fairness in the Marketplace

Early in the century, American consumers lost millions of dollars because so many scales and other weighing and measuring devices were inaccurate. What's more, the states did little about it.

NIST set about to change that. To get the states interested, Louis A. Fischer, chief of the Metrology Division, convened a group of state weights and measures officials in 1905. The meeting was attended by just 11 people. But Fischer persevered, and the group agreed to meet annually and work toward the adoption of uniform laws. The group evolved into the National Conference on Weights and Measures, which today has more than 3,000 participants.

The orderly marketplace of the modern era is ensured by "traceability" to an international system of units. Worldwide uniformity is maintained by the International Bureau of Weights and Measures in France, which oversees a collaborative comparison and updating process under a diplomatic treaty involving 48 nations. U.S. standards are maintained by NIST, which provides calibrations and standards to the states. The states, which are legally responsible for enforcing the standards, check the weights and measures used by business and industry in manufacturing and packaging products, and in determining the quantities of goods sold by weight, measure, or count.

Accuracy in the U.S. marketplace improved considerably over the century. The photo above shows a test car used by NIST in 1913 to test railroad scales in the Northeast. Nationwide uniformity was enhanced further in 1978, when the Institute finished distributing physical standards for weights and measures to 53 states and territories. NIST continues to help the states by accrediting their standards labs, sponsoring the national conference, and providing test protocols and training. NIST also helps monitor fairness in the marketplace, collaborating with other agencies in studies of dairy product packaging, price-scanner accuracy, and other matters.

1905

grated to the United States and became the first superintendent of weights and measures. But the office had few employees, and some people disliked the idea of the federal government imposing standards or anything else on industry.

After strong advocacy by leading scientists and industrialists who endorsed the concept of a national standards laboratory, principally to meet the needs of electrical instrument makers and manufacturers, the U.S. Congress agreed to go along with the idea. NIST originally was part of the Treasury Department, then moved to the Department of Commerce and Labor, later split into two units. The Institute went with the Department of Commerce, where it remains today. Samuel W. Stratton, a professor of physics at the University of Chicago, became the first director, a post he held for 21 years.


THE EVENING STAR, MONDAY, MARCH 11, 190

CORRECT MEASURES

Function of the New Bureau of Standards.

LABORATORY TO BE ERECTED

Prof. Stratton, the Director, Details Need of Establishment.

A HANDICAP REMOVED

A new bureau of the government, authorized by the last Congress, will be established in this city in the near future and will give employment to a number of persons. It is to be known as the national bureau of standards and is to be under the control of the Treasury Department. A separate building for a laboratory, to cost not to exceed $250,000, is to be erected on a site to be purchased at a cost of $25,000.

Mr. Samuel W. Stratton of Chicago has been appointed by the President to be chief of the bureau at an annual salary of $5,000. Prof. Stratton is to have the following assistants, to be appointed by the Secretary of the Treasury: One physicist, at an annual salary of [illegible]; one chemist, at $1,500; two assistant physicists or chemists, each at an annual salary of $2,200, one laboratory assistant, at $1,400; one laboratory assistant, at $1,200; one secretary, at $2,000; one clerk, at $1,200; one messenger, at $720; one en-

Director Stratton.

NIST's founding was described in the March 11, 1901, edition of *The Evening Star*.

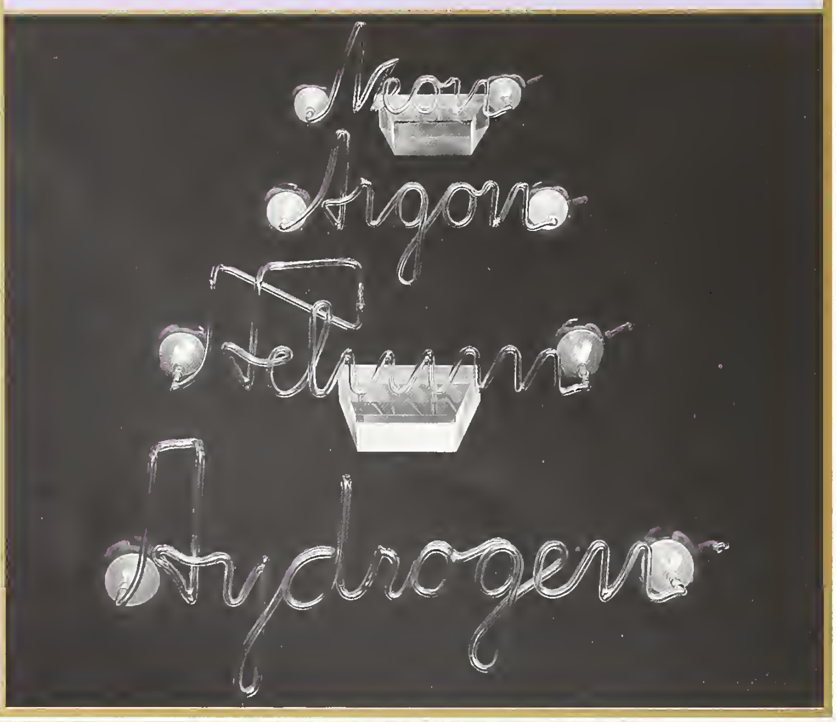
The original staff numbered 12. After several years in temporary quarters, NIST moved to a site on Connecticut Avenue in the District of Columbia, a few miles from the White House. The scientific and technological programs were started from scratch. After improving the standards of electrical measurement, NIST quickly developed better standards of length and mass and new standards of temperature, light, and time. The Institute also established standards of safety in commerce and industry and of performance among public utilities, and it prepared and maintained hundreds of standard samples of materials that helped introduce quality control to U.S. industry. To advance fundamental science, NIST developed increasingly precise instruments, measurement techniques offering greater range than ever before, and wholly new standards such as those for sound, frequency, and radiation.

The need for standards was dramatized in 1904, when more than 1,500 buildings burned down in Baltimore, Md., because of a lack of standard fire-hose couplings. When firefighters from Washington and as far away as New York arrived to help douse the fire, few of their hoses fit the hydrants. NIST had collected more than 600 sizes and variations in fire-hose couplings in a previous investigation and, after the Baltimore fire, participated in the selection of a national standard. ◆

1904

Neon Lights Up in Public

A NIST exhibit at the Louisiana Purchase Exhibition included modified laboratory instruments (glass tubing) containing neon gas, similar to those below. When electricity was applied, the glass tubing lit up with a reddish glow. Although a Frenchman is credited with inventing the neon lamp and obtaining a patent, he did not display the technology in public until 1910. Today, the neon sign industry is worth more than $1 billion.



1915

The Original Consumer Reports

Americans have learned a lot from NIST over the years, from how thermometers work to how to build a radio or conserve energy.

The Institute's original consumer guide, *Measurements for the Household*, was published in 1915. The 149-page guide, based on data gathered in technical studies, described the operation of common measuring appliances such as thermometers and clocks. About 10,000 copies were distributed in three months, more than 30 times the usual circulation of Institute publications of that era. It was the first work of its kind. The journal *Nature* called it a "a treatise on domestic science," the first to demonstrate "the place of science in practical affairs."

In 1917, NIST published *Materials for the Household*, which in both style and content anticipated familiar modern publications such as *Consumer Reports*. Another Institute guide, *Safety for the Household*, was first published in 1918 and showed, for example, the proper way to use a fire extinguisher. These three circulars had a great impact on the public; the Institute was besieged for years with requests for help with problems in the home.

In 1922, NIST fueled the national radio craze when it issued a series of mimeographed letter circulars describing how to build radios. The first one described how to construct a simple crystal detector set for $10; it was so popular that two commercial publishers reprinted it. In 1923, the Institute issued *How to Own Your Own Home*, which sold 100,000 copies the first week. It was reprinted in magazines and serialized in newspapers nationwide.

NIST continued publishing consumer reports through the late 1970s. Its most popular reports of the later era focused on smoke detectors and how to achieve cost-effective energy conservation in a particular home.

The Industrial Age

In the early years of the 20th century, electricity became the power behind American industry. Electric utilities, appliance manufacturers, and communications companies proliferated. This was also the era of industrial development; Henry Ford organized the first U.S. assembly line in 1913.

Most of the values for electrical units available to science and industry were imprecise and tentative, so NIST performed electrical research and testing. Thanks in part to this work, absolute electrical measurements became more accurate than was generally believed possible. The Institute helped improve the accuracy of the values established for the primary electrical units, thereby helping industry make better products and supporting international redefinitions of the ampere, ohm, and volt. NIST also studied underground corrosion of gas mains and water pipes caused by the electric current flowing to city trolleys and came up with almost 20 methods of mitigating this costly national problem.

NIST set to work saving money for the federal government, which bought 1 million incandescent lamps per year and found them quickly burning out. Tests on the lamps showed they did not conform to either the manufacturer's standards or federal specifications. Similar problems were found with a whole catalog of supplies. The Institute tested everything from an elevator cable for the Washington Monument to inks for the Government Printing Office.

NIST conducted life testing research on incandescent lamps as part of an effort to develop standards and specifications.

NIST also performed materials research. In the early years of the century, thousands of train derailments were caused by broken rails, broken wheels, flanges, and axles. From 1912 to 1923, NIST subjected failed parts to chemical, microscopic, and mechanical tests and investigated railroad iron and steel constituents and manufacturing. The Institute reported that the steel industry had not established uniform practices in the manufacture of rails and wheels. By 1930, as better steel went into rails and trains—with NIST's help in standardizing materials and processing—the rate of accidents from these causes fell by two-thirds.

Because the analysis of materials could not be separated from their synthesis, NIST began to acquire experimental factories to study the effects of manufacturing conditions on product quality. These factories became especially useful when World War I began in Europe in 1914. NIST was asked to help address many military needs, from experiments with concrete ships to the testing of various metals to the making of high-precision gage blocks needed to manufacture interchangeable parts. In some projects, the Institute introduced new fundamental principles and concepts of quantitative measurements to industry. By late 1917, shortly before the war ended in 1918, the military services were requesting some sort of scientific work from the Institute every 20 minutes.

Among its accomplishments, NIST helped modernize U.S. aviation. In the decade after the Wright brothers' first flight in 1903, U.S. military forces had only several dozen aircraft, all obsolete by European standards. All sorts of aviation instruments were sent to the Institute for testing, and many were modified or overhauled entirely before being adopted by the military. Institute studies yielded the first quantitative data reported anywhere on the power-producing qualities of fuels. The first serious U.S. studies of the aerodynamics of flight were performed by NIST, which built a wind tunnel with a 2.7 meter (9 foot) propeller that was used to study wind stresses, airspeed indicators, and other instruments.

Both before and after the war, NIST carried out considerable basic research, much of it involving the determination and refinement of physical constants—quantities believed to be the same for all observers and for all time. Some of these were important in science, including standards development, whereas others were needed by industry (the refrigeration industry, for example, needed to know the specific heat of ice) to improve products and processes. By the end of the war, it was clear that scientific methods could contribute to industrial technology, and that fundamental science could have far-reaching consequences at some later time. Industries expanded their scientific staffs; one legacy of World War I was new fields of industrial research.

In its first two decades, NIST won an international reputation for its achievements in physical measurements, standards development, and test methods. Through its standards of measurement, instrumentation, and performance it sought to raise the scientific level of industry. The techniques of mass production introduced during the war gave an enormous impetus to the standardization of methods and materials. ◆

Radio Becomes an Aid to Navigation

Sailors and aviators owe a lot to the Institute, which during and after World War I developed several radio technologies that made navigation much safer.

Among the innovations was a radio direction finder (RDF), a special antenna that determined the direction of radio transmissions. The original RDF was made by an Italian team, but NIST researchers patented an improved design, built in 1916. It served as a prototype for the U.S. Navy and was used widely to pinpoint the positions of enemy forces during the war. By the mid-1920s, many civilian vessels were outfitted with the "radio compass," as it came to be known. The photograph above shows a radio compass and amplifier receiving signals from ships at sea.

In another application of the coil antenna, the Institute disproved the then-common notion that radio communication was impossible under water. In 1917, NIST placed an RDF under water and received signals clearly; it then built a simple but effective radio apparatus for submarines.

The Institute's greatest contribution to navigation was probably the use of radio technology to make the first "visual type" radio beacon for an instrument landing system, which enables an air crew to locate and land on a runway in poor visibility. Indicators on the aircraft instrument panel recorded the signals from strategically placed radio transmitters, enabling the pilot to know the plane's approximate position in three dimensions at all times. The first "blind landing" relying entirely on radio guidance was made in 1931 in College Park, Md. The principles of this design provide the basis for today's air traffic control systems worldwide.

1916

1923

Improving Radio Reception

NIST was one of the first radio broadcasters, initially transmitting music and speech and then pioneering a market and crop report service. The purpose was research, not entertainment; the Institute sought to overcome the technical limitations of this emerging medium. A major problem with early radio was poor reception, caused by interference among stations that veered off assigned frequencies.

To help stations control their transmissions, the Institute estalished a standard of frequency and began broadcasting precise frequency signals over its laboratory transmitter, WWV, in 1923. As shown in the photo on the right, NIST radio station WWV had two transmitting antenna towers in 1923, a short one (on the left) for short waves and another one for standard transmissions. It was the start of a service that continues to this day; time signals were added in 1945.

NIST also performed important research that greatly improved understanding of why radio reception sometimes fades out suddenly. After collecting copious amounts of data, researchers confirmed the underlying problem as solar activity, later correlated with numbers of sunspots. The group's method of predicting sunspot numbers proved useful for decades.

Today, WWV and WWVB (in Colorado) and sister station WWVH (in Hawaii) serve radio and television stations, power and telephone companies, the financial community, scientists and engineers in many fields, computer networks, and navigators. These NIST frequency services enable laboratories to calibrate precision oscillators to an accuracy much better than one-thousandth of a second in three years.

The Roaring Twenties

The United States emerged from the Great War as a rich and powerful nation. American life changed dramatically in the 1920s, which saw the first trans-Atlantic phone call, the first movie with sound, the first enclosed car at popular prices, and the discovery of penicillin.

And suddenly everyone seemed to have a radio. Radio had been a topic of research interest at NIST since its early years, when both the Army and Navy set up separate research facilities at its site to study wireless telegraphy. By the late 1920s there were hundreds of broadcasting stations and nearly 10 million privately owned radio sets in the United States, including quite a few that were handmade using instructions published by NIST. The Institute built the first alternating-current (ac) radio set in 1922, years before commercial firms offered ac-powered radios for the home (earlier models were battery powered). The Institute also helped train radio technicians, published early reference works, and coordinated the writing of an academic textbook that was admired by Thomas Edison as "the greatest book on this subject that I have ever read."

Also booming in the 1920s were the building and construction and automobile industries, both of which received support from the nation's principal physical science

This car, rigged with two pistols, was used to measure a motorist's reaction time in applying the brakes.

research laboratory. NIST recommended revisions aimed at achieving greater uniformity in local building and plumbing codes and zoning regulations and published a popular handbook for prospective home buyers. NIST staff, in partnership with Underwriters Laboratories and the National Fire Protection Association, began developing methods to test the fire endurance of building structures; this work led to test procedures that became ubiquitous throughout the world.

Automobile research focused on two issues that would come to dominate the history of this technology—fuel economy and safety. Amid warnings that the nation's known petroleum reserves would be depleted in as little as 10 years, the Institute helped conserve gasoline by identifying the characteristics of engines, fuels, and oils that enhanced operating efficiency. To help establish safe driving speeds, it also investigated brakes, the braking ability of cars, and the reaction time of drivers in applying brakes.

Meanwhile, NIST became internationally known for its technical prowess. Radium, a radioactive element used in medical treatments, became so expensive that its discoverer, Marie Curie, had a difficult time obtaining enough for her own studies. American women raised money to buy some for her and, in 1921, Madame Curie visited the United States to receive a gram of radium from President Warren Harding. It came with a certificate from the Institute attesting to the purity and radioactivity of the sample.

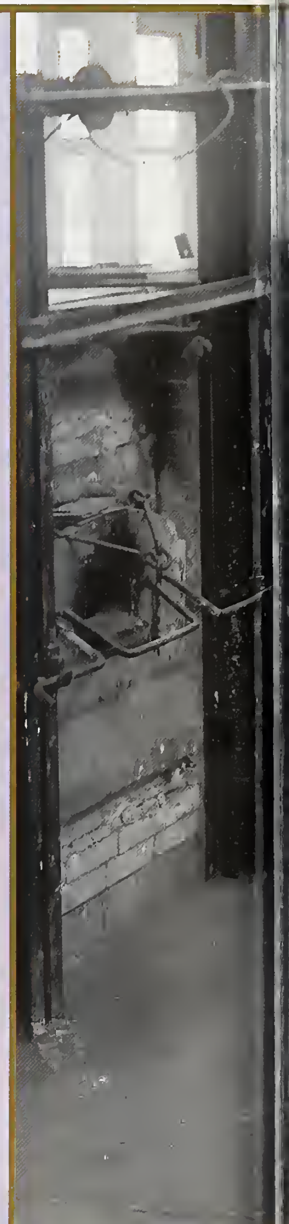
1928

All the Better to See You With

Relying on foreign technology is risky. The United States learned this lesson early in the century when it imported all its high-quality optical glass and instruments, and World War I suddenly cut off the supplies. The situation was so dire by 1917, when America entered the war, that citizens were asked to lend their binoculars and field glasses to the military.

So NIST began studying the manufacture of optical glass, a mixture of silica and chemicals melted in a clay pot, which often deteriorated and contaminated the glass. After more than a year's work, the researchers produced a superior clay pot, greatly reducing the difficulty, time, and cost of making these containers. The Institute made nearly 7 metric tons (15,000 pounds) of eight types of glass during the war, continuing its crucial research and production through World War II and into the 1950s.

The most ambitious undertaking in the history of the Institute's glass plant was the casting of a 1.8 meter (69.5 inch) disk—then the largest in the nation—for the mirror of a large reflecting telescope. No other U.S. plant was equipped to do it. Four disks were poured that cracked during cooling. The fifth one, poured in 1927 and pronounced a success the following year, was cooled very slowly, by as little as 1 degree per day. The 1.7 metric ton (3,800 pound) disk was subsequently presented to Perkins Observatory at Ohio Wesleyan University. This success influenced the Corning Glass Works in casting a 5 meter (200 inch) mirror for what became the largest optical telescope in the world, at Palomar Observatory in California.



While helping to enhance the quality of commercial products, the Institute also helped create new industries. After German sources of cane and beet sugar (sucrose) were cut off, for example, NIST scientists recreated the manufacturing processes to prepare small samples of corn sugar (dextrose) and other rare sugars for standardization and testing purposes. They also looked for ways to reduce costs, eventually developing a process for large-scale manufacturing of almost chemically pure, low-cost dextrose, which then became an industry unto itself. A spinoff of sugar research was the discovery of practical uses for process wastes. NIST developed products such as wall and insulating boards made from cornstalks, an early example of recycling.

Another way of making the most of American products was standards. High quality made a difference, too. In the 1920s, NIST standards became official federal standards, unifying the specifications of some 40 government purchasing agencies and achieving greater economies in supplies. The Institute quickly prepared specifications for items such as fire hoses, pneumatic tires, and shoe sole leather and recommended simplified practices, such as reducing the number of milk bottle designs from 49 to nine. American industry saved tens of millions of dollars through simplification. Standards also reduced the price of incandescent lamps from $1.30 to 16 cents. Then came the stock market crash in 1929 and the Great Depression, ending the crusade for a time. ◆

The Depression

By 1932, U.S. unemployment reached almost 25 percent of the labor force. Car sales slumped, nightclubs closed, and hobbies boomed. NIST incurred substantial cuts in research funding and staff. Some professional staff refused their imposed furloughs, preferring to work without pay. Because industry called on NIST (and national laboratories abroad) less often than before, the Depression years were a time of international conferences, interlaboratory comparisons, and exchanges of data and equipment looking to develop new or improved international standards. For instance, NIST and an industry standards association agreed on a new ratio between the inch and the millimeter so that precision measurement would be on the same basis in England and the United States, an aid to American exporters.

Despite cutbacks in industrial research, many fundamental studies, such as the development of photometric units (for measuring visible light according to the sensitivity of the human eye) and research on radiation and spectroanalysis, advanced during these years. This work was useful to both science and industry and won wide acknowledgment. Some NIST research in applied technology was terminated; there was a continuing debate over how far the Institute should venture into these areas.

But it did venture into uncharted territory nonetheless. The advances in aeronautics and radio in the 1920s led to a period of worldwide exploration during the 1930s, with trips to Antarctica and balloon flights into the stratosphere sponsored by the National Geographic Society. In 1936 from the USSR, NIST made the first natural-color photographs ever of a total solar eclipse, using a custom-made camera and lens. Many precision measurements then were being made in terms of light waves. With international agreement on definitions and advances in spectroscopy enabling the search for superior types of light for this purpose, it was hoped that many difficulties impeding the international interchangeability of parts might be solved. NIST developed a method for the use of cadmium and krypton wavelengths in the measurement of precision gage blocks that permitted their certification to an accuracy three times better than before.

1931

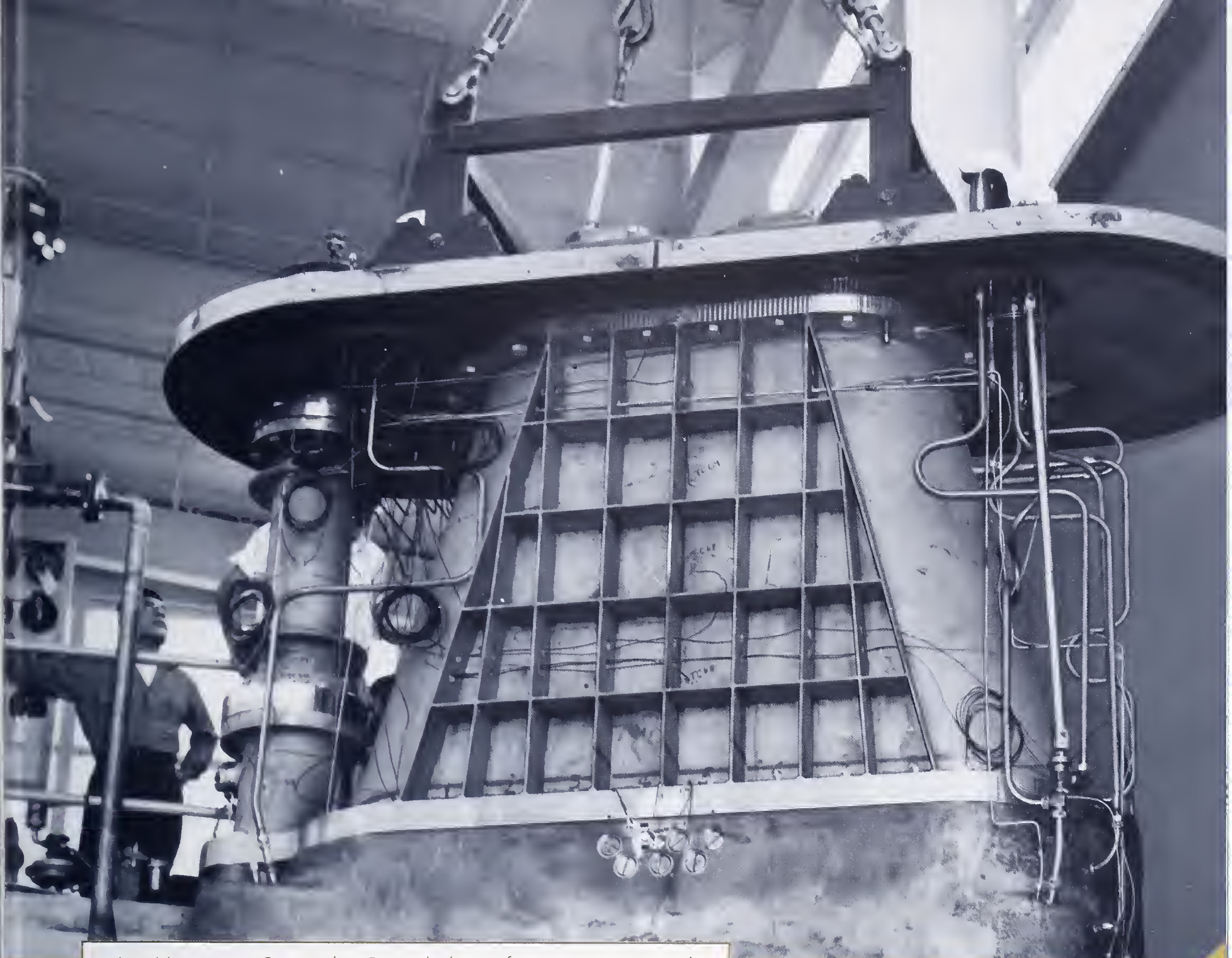
First, Do No Harm

Radiation has been used in medical diagnosis and treatment throughout the century. But it was not until NIST became involved in providing physical measurement standards for radiation that this tool could be relied on to do more good than harm.

Early in the century, technicians operated X-ray equipment empirically—and without lead shielding—at somewhat arbitrary voltages. The need for standard dosages became clear after World War I, with wider use of more powerful X-ray apparatus for cancer therapy and frequent injuries to equipment operators. There also was concern about radium, a radioactive element used in surgery and dermatology that began appearing in consumer products.

In 1926, the Radiological Society of North America asked NIST to determine national standards for radium and X-rays used in diagnostic and therapeutic procedures. The Institute developed the new standard for X-ray exposure, which could be measured precisely, and produced the first quantitative data on X-ray doses in this country. Working through a national committee, NIST helped bring about the 1931 X-ray safety code, which set guidelines for the shielding of operating rooms and high-voltage equipment and for protective devices for patients and operators.

Radiation measurement work continues today. In the 1970s, NIST set up a program to assure accurate doses of radioactively tagged drugs used to diagnose or treat disease. The program tightened the system for measuring dosages and, according to an economic analysis, has a benefit-to-cost ratio of 97 to 1. NIST currently provides national standards for the 11,000 U.S. mammography facilities and is the only laboratory in the world offering an advanced calibration service—based on a radiation detector 100 times more sensitive than the previous one—for checking the radiation dose in seeds used to treat prostate cancer.



A Very Cool Field of Research

Within a few years of its founding, NIST purchased a hydrogen liquefier and began research on cryogenics, a branch of physics dealing with the production and effects of very low temperatures. Over the century, this research has contributed to scientific, military, aerospace, industrial, and medical fields.

First, the Institute devised a standard method of producing liquid and solid hydrogen at a temperature of about −259 °C (−434 °F), not far above absolute zero. In 1931, using the same apparatus, NIST produced America's first liquefied helium (the coolant used decades later in magnetic resonance imaging, or MRI). By mid-century, NIST was established as the federal expert on cryogenic engineering and published the classic book on the subject.

In the 1950s, NIST designed and constructed the world's largest hydrogen liquefier for the Atomic Energy Commission's nuclear fusion devices. The liquefier provided liquid fuel for the first hydrogen bomb, which was tested successfully. The Institute also began providing data and models to the National Aeronautics and Space Administration (NASA), which wanted liquid hydrogen for use as missile and satellite fuel. For the University of California at Berkeley, NIST helped construct a liquid hydrogen "bubble chamber" (see photo above)—the largest ever at the time—later used in Nobel Prize-winning research by physicist Luis Alvarez .

To meet the needs of industry, NIST gathered data on other cryogenic fluids used in steel and glass manufacturing, freezing of food, and other processes. Institute research on cryogenic refrigerators led to commercialization of this technology, which is used in NASA and Air Force satellites. In addition, NIST research on critical currents in superconductors has contributed to the design of superconducting magnets used in MRI systems and other applications.

1931

1935

The Nation's Crime Laboratory

For about two decades, NIST was the principal U.S. crime laboratory. The investigations were led by Wilmer Souder, a scientist who became interested in crime detection in about 1913. By the early 1930s, he was participating in 50 to 75 federal investigations annually involving extortion, kidnaping, forgery, and other crimes.

His most famous case was the kidnaping of aviator Charles Lindbergh's baby in 1932. Souder was one of several handwriting experts who independently identified the ransom notes as having been written by Bruno Richard Hauptmann, who after his conviction in 1935 reportedly said: "Dot handwriting was the worstest thing against me."

When the Federal Bureau of Investigation (FBI) hired its first scientist in 1932, Souder helped establish the new crime lab and lectured the trainees on various investigative techniques. When he retired from NIST in 1954, *The Washington Post* called him "one of the nation's best but ... least known criminologists."

NIST continues to assist law enforcement agencies. More than a dozen law enforcement standards have been issued since the early 1970s. One of them, a standard for ballistic resistance of police body armor, is used by companies that sell bullet-resistant armor to police and the military worldwide. Not a single police officer wearing body armor made to these specifications has been killed by penetration or blunt trauma.

NIST also has worked with the FBI for more than 30 years to improve fingerprint screening. After helping to design the first hardware for that purpose, in 1995 NIST created the first successful computer program that automatically classifies about 80 of 100 fingerprints into five categories. In addition, Institute researchers wrote standards for the exchange of fingerprint data among agencies, enabling real-time electronic distribution of images and information that has accelerated judicial processes.

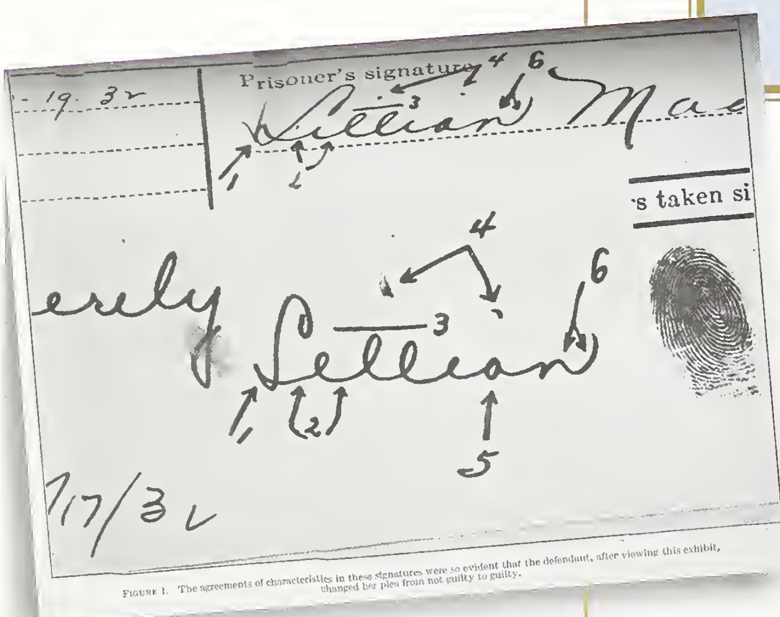


FIGURE 1. The agreements of characteristics in these signatures were so evident that the defendant, after viewing this exhibit, changed her plea from not guilty to guilty.

NIST began a tradition of contributing to Nobel Prize-winning research by other scientists when its cryogenics lab was used to confirm the existence of deuterium, or "heavy hydrogen." This isotope of hydrogen was discovered by a guest researcher, who subsequently won the Nobel Prize in chemistry. A NIST scientist separated the isotope. These scientists expected that deuterium would be useful for research or practical devices such as neon signs; they had no idea that it would later become a vital ingredient in the making of nuclear bombs.

In work of interest to the general public, NIST supported the consumers' movement of the 1930s by advising consumer labs on test instruments and equipment and devising new ones. Following magazine articles and publicity about its work, NIST was deluged with letters from the public asking for assistance on all types of problems, from increasing the birth rate of pigs to obtaining devices to locate buried treasure. In a single three-day period in 1939, almost 800 letters arrived requesting technical information, along with a similar number of telephone calls, 459 letters asking for publications, and 429 visitors asking for scientific or technical information. ◆

1936

Better Weather Forecasting

To help out the Weather Bureau and Navy, NIST built a radiosonde, a balloon-borne instrument that greatly increased the range and quantity of available weather data. Effective up to heights of 24 kilometers (15 miles) or more and distances up to 322 kilometers (200 miles), the radiosonde transmitted continuous data on cloud height and thickness, temperature, pressure, and other phenomena. By 1940, it was an integral part of U.S. weather forecasting, and some 35,000 units were being built each year. In 1938, NIST developed a device that made possible, for the first time, accurate measurements of humidity. Radiosondes still are used today.

World War II

Launching the Synthetic Rubber Industry

Synthetic rubber became a precious commodity during World War II when imports of natural rubber from the Far East were cut off. Indeed, natural rubber became so rare in the United States that gasoline was rationed to discourage people from driving cars (which, of course, ran on rubber tires). Ultimately, the nation spent as much on its rubber program as it did on the atomic bomb.

NIST helped win the rubber battle in several ways. As the government purchased any natural rubber it could find from South and Central America and Africa, NIST set up a lab to test and grade these rubbers and helped the Brazilian government organize its own lab to do the same.

The U.S. government also organized a consortium to study synthetic rubbers and invested in the construction of 15 production plants, which had to produce rubber that met uniform specifications. Prewar NIST work on the thermodynamics of rubber suggested which types of synthetics to use and how to test them.

Beginning in 1943, the Institute helped standardize both physical and chemical testing, resulting in a notable improvement in the accuracy of rubber testing. NIST also helped develop tests (such as the use of freezing points to determine material purity) and improve instruments (such as the viscometer) later used in synthetic rubber plants.

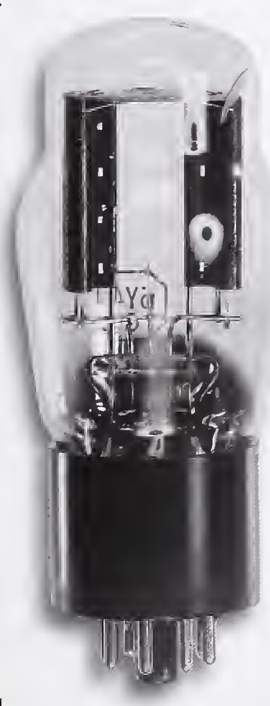
Today, the U.S. synthetic rubber industry reports more than $4.5 billion in annual shipments, and the nation exports substantial amounts of these materials.

1943

Science and technology assumed paramount importance during World War II, as illustrated most dramatically by the development of the atomic bomb.

Just before the war, scientists found that, by bombarding uranium atoms with neutrons, they could split the nucleus, releasing huge amounts of energy. Fearing that the Germans would be the first to discover how to put nuclear fission to practical use, Albert Einstein, along with Leo Szilard of Columbia University, sent a letter to President Franklin Roosevelt, explaining the significance of the experiments and the need to be first in overcoming this challenge. The letter was transmitted shortly after Germany started the war by invading Poland.

President Roosevelt consulted NIST Director Lyman J. Briggs, his principal official counselor on scientific matters, and then appointed an advisory committee chaired by Briggs to look into the question of uranium fission. The committee reported that the energy produced might be useful for a new explosive as well as a new power source for submarines. In early 1940, the first funds were made available for research on what became the atomic bomb.



While many university scientists studied different aspects of the problem, dozens of NIST staff members carried out important initial research. The Institute served as a central control lab for determination of the properties of uranium; the staff also found a way to remove virtually all impurities from uranium oxide and developed analytical procedures for controlling the purity of critical materials used in nuclear reactors and bombs. Eventually, development and engineering tasks were transferred to the military's Manhattan Project.

The bomb work was classified. By 1940—before the United States officially entered the war—NIST had so many confidential projects under way that Briggs obtained authority to close the street running through the campus, and fences went up around the grounds. By 1943, the entire staff was engaged in war work. They calibrated gage blocks; tested quartz crystals used in radio equipment; made effective coatings for everything from munitions to matches; developed new metal alloys; designed carbon monoxide indicators for fighter plane cockpits; and tested new plastic products and textiles. In addition, researchers developed a method for making special paper for war maps that was used extensively, one of many NIST achievements over the years in paper research (including techniques for making durable U.S. currency).

The war also drew NIST into the increasingly important field of electronics. NIST weapons research led to a contractor's development of printed circuits, which substituted printed wiring, resistors, and coils for the conventional discrete components in electronic devices. This technology contributed to a new field of electronic miniaturization for which the Institute provided useful engineering data and components. Among its contributions, NIST built a rotary printer that applied printed circuits on either flat or cylindrical surfaces.

During and after the war, federal officials came to recognize the importance of supporting the basic research that made useful applications of science and technology possible. At the same time, research costs became so great that government support was critical to the nation. NIST was thus a key player in the scientific revolution, along with new federal institutions such as the Office of Naval Research and the National Science Foundation. ◆

1944

Early "Smart" Weapons Go to War

NIST helped the Allies win World War II by assisting with numerous military projects, most notably the design of two early "smart" weapons systems.

One was a fuse that exploded a projectile when directly over its target, rather than on impact, making the weapon five to 20 times more effective. The "radio proximity fuse" designed by NIST was a tiny radio transmitter and receiver about the size of a lightbulb, powered by batteries or generators. Variations on the device were designed for rockets, shells, and bombs. Hundreds of workers spent several years perfecting the technology, first tested in early 1941.

The fuse, often described as a leading technical advance of the wartime period, was not released for general use until 1944. Mortar shell fuses did not go into full production, but fuses for rockets and bombs went into full production and were used extensively. The first major combat use of the fuse was during the pre-invasion bombardment of Iwo Jima in 1945. Some 8.3 million fuses were produced.

NIST also helped design and construct the Bat, the first fully automated guided missile ever used successfully in combat. In addition to coordinating civilian agencies' work on the Bat, NIST worked out the aerodynamic and stabilization characteristics of the 454 kilogram (1,000 pound) missile, which emitted shortwave radiation and was guided by the radar echoes of the enemy target. In addition to its self-guidance capability, the Bat was known for its long range, high accuracy, and high payload. It was used in the Pacific theater.

Postwar Years

After the war ended in 1945, Americans confronted price inflation, labor strikes, and shortages of food, cars, and homes. But the situation improved rapidly, as the shortages were remedied by expanding industries. Veterans received low-interest home loans and a building (and baby) boom began. New technologies, such as jet aircraft and the transistor, entered the marketplace, transforming the U.S. economy and way of life.

The next external threat was seen in Communism. The phrase "Cold War" was coined in 1947; two years later, an atomic device was detonated by the USSR. In 1950, Communist North Korea invaded South Korea. The U.S. participation in these conflicts sustained public funding of science. For national defense projects, NIST acquired many new tools, including an early electron microscope for research in metallurgy and electron optics; a mass spectrometer for measuring nuclear masses; and an ultrasonic laboratory for using sound waves to study the properties of gases and liquids.

NIST was a natural leader in the new science of instrumentation. An underwater velocimeter developed with the Navy became the standard instrument for recording speed-of-sound profiles in the ocean; it had many tactical uses, such as in sonar, and also was used by oceanographic institutions. In addition to inventing research instruments, the Institute served as a corporate lab for the government by developing practical tools such as a physiological monitor that sensed blood pressure, heart, and respiration; free-floating weather buoys that broadcast data on wind, pressure, and temperature and were operable in hurricanes; and an electronic currency counter,

1949

The "Atomic Age" of Time Begins

Time took on a new look and a new role at mid-century, and NIST, which maintains the nation's primary time standards, played a leading role in the transition.

From the pendulum to the quartz clock, timekeeping had improved in the past. But NIST's operation of the first atomic clock in 1949 led to giant leaps in accuracy. Atomic clocks are based on the resonances, or vibrations, of atoms or molecules. (Some have called NIST's innovation a molecular clock, because it was based on resonances in the ammonia molecule, which contains four atoms. But the principle is the same.) NIST's achievements in this field later were cited as advancing the research of three 1989 Nobel Prize winners.

The performance of the Institute's original clock was only slightly better than existing standards, but the precedent was set. Attention then shifted to the cesium atom, which by 1960 was incorporated into the world's official timekeeping system. Cesium clocks now keep time to an accuracy of about one second in 20 million years. These advances in performance of atomic clocks have supported the development of new technologies, such as high data rate telecommunications and the Global Positioning System. Accurate timekeeping will become even more important in the future as the speed of electronic systems increases, requiring commensurate improvements in levels of synchronization.

Today, NIST's atomic clocks are used for many purposes, including the synchronization of Los Angeles traffic lights and guidance of deep space probes. The National Association of Securities Dealers requires that all electronic transactions be stamped with a time traceable to NIST. An Internet time service that allows users to synchronize their computers' internal clocks with NIST's atomic clock was receiving 30 million "hits" per day as of mid-2000, and the number was growing rapidly.

Safeguarding the Charters of Freedom

1950

To guard against deterioration, the original parchment manuscripts of the Declaration of Independence, the Constitution, and the Bill of Rights were sealed using a preservation technique developed at NIST in cooperation with the Libbey-Owens-Ford Glass Company and Library of Congress. The helium-filled cases are still in use. Today, NIST is involved in a project with the National Archives to transfer the Charters of Freedom to argon-filled enclosures, allowing for the use of advanced measurement techniques to monitor conditions inside the glass.

estimated to save the government almost a quarter of a million dollars annually.

Perhaps the most important new tool was the computer. An automated electronic computing project was established at NIST in 1946, about the time that the Electronic Numerical Integrator and Automatic Computer (ENIAC), the first all-purpose electronic computer, began operating at the University of Pennsylvania. In 1947, NIST began building computers for other government agencies; these machines would be used for tasks such as predicting radioactive fallout after a nuclear explosion. The Institute also began building an "interim computer" for itself. This machine, the Standards Eastern Automatic Computer, was successful enough to become a full-scale machine and one of NIST's major achievements in computing. NIST staff members also developed a mathematical algorithm, used to solve very large systems of linear equations, that nearly 50 years later would be named one of the top 10 algorithms of the century by a computing trade journal.

In 1950, NIST still was based in the District of Columbia, but it also had work under way at 23 other locations. For example, it operated four stations for cement testing in Pennsylvania, Washington, Colorado, and California; two proving grounds for weapons testing in Maryland and New Jersey; a railway scale test car based in Illinois; a station to certify government purchases in Massachusetts; and nine field stations for studying radio wave propagation spanning the northern hemisphere, from Alaska to Hawaii. The need for additional laboratory space led to the establishment of a cryogenic engineering laboratory and radio facilities in Boulder, Colo., on an 89 hectare (220 acre) tract donated by citizens.

NIST research was equally far flung. Continuing its early studies of underground corrosion, NIST exposed specimens of materials in 128 test sites around the nation, representing all major types of U.S. soils. Metal samples were buried, periodically unearthed, and assessed. By the 1950s, these studies had extended to other types of environmental corrosion. In 1957, a report was published on the underground sites that became virtually indispensable to the corrosion engineer. In the following years, NIST continued to help American con-

President Dwight D. Eisenhower delivered the dedication address at NIST's campus in Boulder, Colo., in September 1954.

1953

NIST Is Tested—and Wins

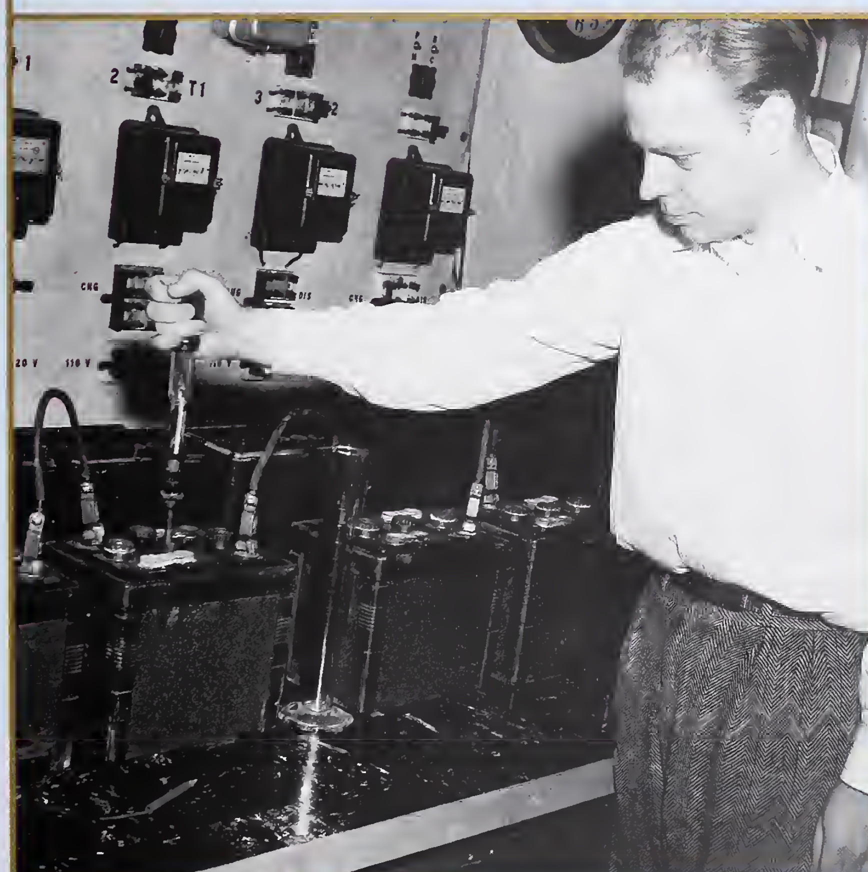
Testing of commodities purchased by the federal government, a very small part of NIST's work after World War II, led to one of the Institute's biggest controversies and some of the earliest debates on the role of science in public policy.

Before the episode ended with the NIST's vindication in 1953, there were attacks on the Institute's technical work, investigations by two high-level committees, hearings before a U.S. Senate committee, debates over the definition of scientific truth, the forced resignation of Director Allen Astin (later reinstated) and a staff mutiny over it, and the resignation of an Assistant Secretary of Commerce.

It all began innocently enough. As part of its long-term research on batteries, NIST tested batteries and additives for other units of the government. No additive was ever found to be beneficial. NIST did not ordinarily name commercial products, endorse them, or permit its tests to be used for advertising, but a series of events (including a request from a senator) converged to require tests of a battery additive marketed as AD-X2.

The manufacturer claimed AD-X2 would improve lead-acid battery performance and, under some circumstances, revive a dead battery. NIST's laboratory tests found the product was not effective. But there were many satisfied users, and it was suggested that the government was persecuting a small manufacturer, which incidentally had some strong allies. For a time, these allies appeared to include the Massachusetts Institute of Technology, which ran its own tests.

After many tense months, the controversy was finally resolved when a committee of the National Academy of Sciences—the nation's highest scientific authority—supported NIST's findings on AD-X2. Furthermore, the Academy found that the Institute's work on this case had advanced the science of electrochemistry by at least a decade. Through it all, NIST maintained its integrity in the face of intense public scrutiny.



Better Dental Tools and Materials

Nobody likes visiting the dentist, but it could be worse. For instance, getting a cavity fixed would take longer and be more uncomfortable if those drills were much slower, as they were in the 1940s before researchers at NIST made the prototype for today's high-speed drills.

As part of an Institute collaboration with the American Dental Association (ADA), researchers developed the hydraulic turbine dental handpiece, which attained a speed of 61,000 revolutions per minute—almost 10 times that of a conventional drill—without vibrating or overheating. This 1953 invention inspired the later development of air turbines, which set the stage for even higher speeds. The hydraulic handpiece, which was given to the Smithsonian Institution in 1964, had an almost unimaginable benefit-to-cost ratio of 27,000 to 1, according to an estimate made in the 1960s. Not to mention happier patients.

The drill was just one product of the collaboration with the ADA, which began in 1928 and continues today. In the 1940s, researchers found the first explanation of post-operative pain (delayed excessive expansion of dental amalgam), thus making it possible to eliminate the pain. In the 1950s, the team developed a panoramic X-ray machine (see photo above), which made it possible to take a picture of the whole mouth with only one exposure, significantly reducing the radiation doses to oral tissues. It remains in use today by the military and many dentists. And the development of composite filling materials and dental adhesives has been important both aesthetically and economically.

sumers and industry combat corrosion, estimated to be a problem costing $70 billion annually by the early 1970s. Internationally renowned for its expertise in this field, NIST has worked on corrosion projects of all types and scales, from helping the nation of Kuwait understand and eliminate the development of holes in its water pipes to suggesting alternative materials to solve corrosion problems at the White House.

As new industries evolved in the postwar era, innovative measurement techniques were needed. In 1955, an Institute electronics scientist was assigned a $10,000 project to determine what support could be provided to the transistor industry. An early problem was the measurement of silicon resistivity, a key property of semiconductors governing device design and manufacturing. Measurement discrepancies within and between companies were too great for acceptable quality control, so NIST developed a non-destructive measurement method that was an order of magnitude better than existing practice. This work provided the basis for five industrial standards and produced economic benefits to industry exceeding 100 times the cost of the research; it also established a NIST partnership with the semiconductor industry that continues to this day.

1953

Pioneering Modular Electronics

Tinkertoy meant a lot more than child's play at NIST in 1953, when a project named after the toy construction sets mechanized the production of modular electronics, a step toward the ubiquitous microelectronics of today.

Project Tinkertoy was intended to help ensure national preparedness in emergencies by drastically reducing production lead time and enabling rapid conversions from civilian to military products. The Navy selected NIST to lead the project because it offered the "most advanced state of processed circuitry." The Institute already had developed a modular design concept and engaged in pioneering work in printed electronic circuits.

In Tinkertoy, automatic machinery attached basic electronic components to ceramic wafers and stacked the wafers into modules, which then were assembled into complete units. The modules were compact and reliable—so rugged that a demonstration radio could be flung against a wall and still play. NIST performed the basic research and development and designed a pilot plant; various companies designed and built the equipment and ran the production line. The manufacturing cost was estimated to be 44 percent lower than conventional processes.

Dubbed the outstanding development of 1953 by the journal of the Society of Manufacturing Engineers, the Tinkertoy process was used to make sonar buoys for detecting enemy submarines. The project also contributed to the development of the first metal-ceramic vacuum tubes. But the fabrication equipment was complex, and the concept was quickly supplanted by transistors and printed circuit boards, to which some of the individual Tinkertoy components were applied.

An ellipsometer was used to investigate the role of thin films in corrosion.

Tests performed with this mechanical comparator provided data on the stability of gage blocks developed by NIST.

1954

PROFITABLE IDEAS: THE FIRST "READING MACHINE"

Jacob Rabinow could turn just about any idea into a functional piece of equipment. So it was with his reading machine, one of about 230 inventions patented by the NIST engineer and the forerunner of the optical scanners used by banks and post offices today. Cited as his best-known invention by the Lemelson-MIT Prize program, which honored Rabinow in 1998 for his lifetime achievements, the original reading machine is on permanent display at the Smithsonian Institution.

Rabinow got the idea for machine reading, or "optical character recognition," when a friend went blind in the late 1930s. Later, he convinced his boss at NIST to let him build a reading machine. The resulting machine read the alphanumeric output of a portable typewriter, pioneering the "best match" approach by comparing each character on a printout to the entire alphabet and determining which letter was most similar. "It enabled us to read very poor printing that could not be read by any other means," Rabinow said.

The machine read one character per minute—to the cheering of onlookers. By comparison, today's machines can recognize up to 10,000 characters per second.

The reading machine is just one of many novel technologies nurtured by NIST, which long has encouraged innovation by industry and the public as well as its own staff. NIST took on an official role in encouraging private-sector innovation in 1940, when it was assigned to support the National Inventors Council (NIC), formed by the Secretary of Commerce to promote defense-oriented invention. NIST performed evaluations through 1964. During those years, more than 340,000 ideas were evaluated by the NIC, and many were referred to defense agencies for support; the mercury battery for "walkie-talkies" was a notable result. From 1964 through 1974 NIST provided an information and referral service for inventors.

Legislative action in 1975 again assigned the Institute a similar official role, this time in encouraging energy-related invention. From 1975 through 1998 under the Energy-Related Inventions Program, NIST solicited and evaluated more than 32,000 ideas, recommending more than 700 for U.S. Department of Energy support. By 1998, NIST-recommended inventions reaching the marketplace had generated more than $1 billion in sales and saved sufficient energy to light 10 million homes for a year.

The Fall of Parity

The rules of physics were rewritten when a difficult experiment at NIST showed, strikingly and convincingly, that in at least one fundamental physical process, the world is distinguishable from its mirror image. Physicists long had assumed the opposite, constructing their theories so that the corresponding mathematical property, parity, remained unaltered in all subatomic processes. Thus, this experiment brought about "the fall of parity" from the ranks of well-conserved physical quantities such as energy and momentum. The results verified theoretical work in quantum mechanics that won physicists at Princeton and Columbia universities the Nobel Prize in physics. The experiment at NIST was conducted by (pictured, left to right) Ralph Hudson, Ernest Ambler, Dale Hoppes, Raymond Hayward, and (not pictured) Chien-Shiung Wu of Columbia University.

1956

The new age of science and technology challenged the Institute to provide a host of new fundamental physical standards, physical constants, and standard reference data. A standard was developed to measure the emission rate and flux associated with neutron sources, greatly improving accuracy and making interlaboratory comparisons possible. This standard proved valuable in the operation of nuclear reactors and in conducting neutron irradiation research, such as that later performed at NIST. A small device called an omegatron was developed, enabling scientists to determine the value of the Faraday constant—which is basic to the definition of the ampere—using a high-precision physical method instead of electrochemical experiments. And an Institute compilation of accurate values for the thermodynamic properties of many compounds, in a format that allowed prediction of the outcome of thousands of chemical reactions, became immensely important in industry as well as scientific research and education; government efforts to develop high-performance rocket engines, for instance, drew heavily on these data.

The 1950s saw a steady increase in high-rise housing, office buildings, and federal buildings throughout the United States. NIST addressed many aspects of building technology, including new structural designs, structural strength, fire resistance, acoustics and sound insulation, heating, ventilation, air conditioning, and building and electrical equipment. Research on thermal insulation led to the evaluation of aluminum foil reflective insulation and was partially responsible for the wide acceptance of glass wool insulation with an aluminum-foil/paper surface.

In 1957, NIST coordinated data collection for the International Geophysical Year, which involved as many as 20,000 scientists from 67 countries in a study of the Earth and its atmosphere. The year was chosen to coincide with a period of maximum sunspot activity. The Institute

1957

Pioneering Computer Launches New Era

Humming along at 1 megahertz and offering 6,000 bytes of storage, NIST's Standards Eastern Automatic Computer (SEAC) was a marvel at the dawn of the computer era, introducing many "firsts" and demonstrating early applications of the technology that defined the late 20th century. Dedicated in 1950, SEAC was the first operational, internally programmed digital computer in the United States. It served the government for more than 13 years, handling tasks such as Air Force planning, Social Security accounting, and checking of calculations for the design of the hydrogen bomb.

Its engineering innovations included electric typewriters and retooled teletype machines as input-output mechanisms, new memory mechanisms using ultrasonic technology, and a graphical display that produced the first computerized image in 1957. To input that image, NIST researchers built the first scanner, a simple rotating drum to trace variations in intensity over the surfaces of photographs.

When a 5 centimeter (2 inch) square picture of NIST engineer Russell Kirsch's son was scanned into SEAC, it launched the field of image processing, which today has applications ranging from satellite imaging to desktop publishing. Kirsch also demonstrated early artificial intelligence and timesharing applications and wrote the first "picture grammar" (programming rules for combining pieces of a picture to form a complete image).

1958

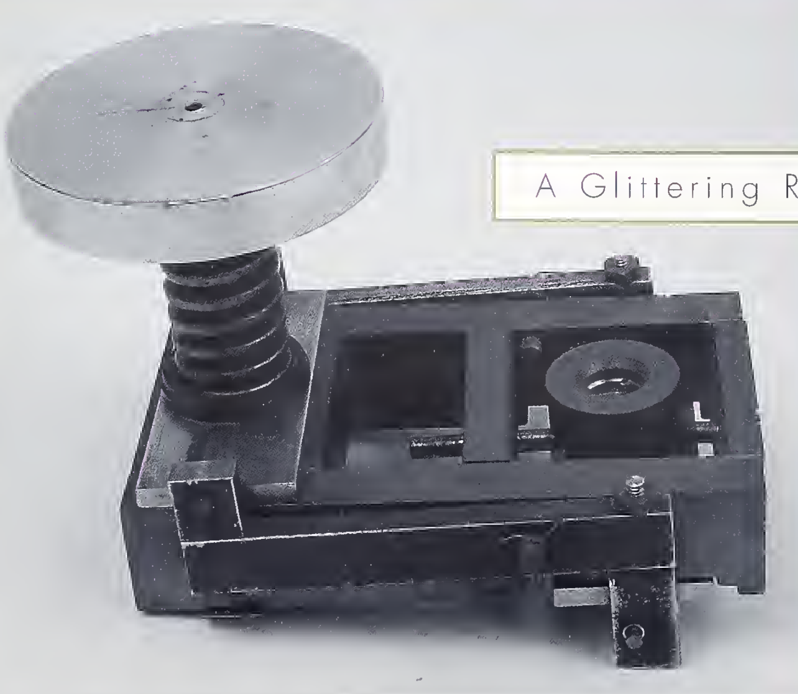
Achievements in Spectroscopy Pay Off

Much of what is known about the universe has been learned through spectroscopy, a technique for identifying and characterizing the substances present in stars and other objects based on the characteristics of the emitted light, which depend on the energy levels of the atoms. And much of what is known about spectroscopy can be attributed to NIST. Among its greatest contributions is *Atomic Energy Levels*, three volumes published between 1949 and 1958, which are still considered models of authenticated, verified, consistent data. Earlier compilations were incomplete and inadequate for many applications.

NIST's highly reliable data had a swift impact on, for example, the development of gas lasers. Arthur Schawlow, who with Charles Townes wrote the 1958 paper that launched the laser field, credited the data with assisting the pair in their early selection of materials that could lase. "The [NIST] tables have been, and are continuing to be, essential tools in the search for new laser materials and new wavelengths," Schawlow wrote in 1971. (Both men won Nobel Prizes for other scientific achievements.) In all, the NIST volumes have been cited by others about 13,000 times, more than enough to be considered "citation classics."

The data were compiled by Charlotte Moore, one of few professional women at NIST in those days, with great persistence, initiative, and attention to detail. Under the direction of William F. Meggers, she gathered published and unpublished data from many sources and, when data were missing, located the appropriate experts and asked them for help. Her work served as a model for NIST's more recent atomic data compilations, which have included a fourth volume of energy levels for the rare-earth elements published in 1978.

received visual, optical, photographic, photometric, and radio observations of the solar activity from all over the world and maintained a constant account of the state of the sun. During periods of unusual activity, alerts were sent to scientists across the globe. The Institute also performed scientific studies of the ionosphere and radio propagation as well as satellite observations. Within 12 hours after Russia launched Sputnik I, NIST modified existing equipment to receive signals from the satellite. ◆



A Glittering Research Tool

A NIST research team invented the diamond-anvil apparatus, which can compress samples to ultrahigh pressures. The designers used single-crystal diamonds (confiscated by the U.S. Customs Service) as the compressing surfaces because of their great hardness and transparency to light. Similar devices, together with a technique developed at NIST for measuring pressures inside the sample chamber, are used today by scientists worldwide. Applications include studies of the effects of pressure on solids, liquids, and gases using a wide variety of scientific measurement techniques.

NIST made this mercury lamp available to science and industry as an ultimate standard of length in 1951. Length measurements were based on the circular "interference fringes" seen in the background.

The Physics of Baseball

After he retired, former NIST Director Lyman Briggs used a wind tunnel he designed in 1918 and the pitching staff of the Washington Senators to settle a long-disputed question: the degree to which a baseball can be made to curve in the 18 meter (60 foot) throw from the pitcher's box to the plate. He found that the spin rather than the speed of the ball determined its break. Briggs described his research—widely reported in the news media—as a logical development in the field of mechanics and closely related to NIST work in ballistics and projectiles.

The Space Age

The 1960s were a time of social turmoil, marked by the civil rights movement, political assassinations, the Vietnam War, and the antiwar movement. But it was a golden age for science, with ample funding and broad industrial and public support.

The launch of the satellite Sputnik I in 1957 precipitated the space race. The National Aeronautics and Space Administration was formed, and, in May 1961, President John F. Kennedy committed the nation to landing a man on the moon and returning him safely to the Earth. The U.S. space program required new measurements of the combustion of missile fuels and of rocket thrust in the million-pounds range, as well as the effects of extreme and sudden changes in temperature and pressure on materials and mechanisms of rocket engines. NIST was

1960

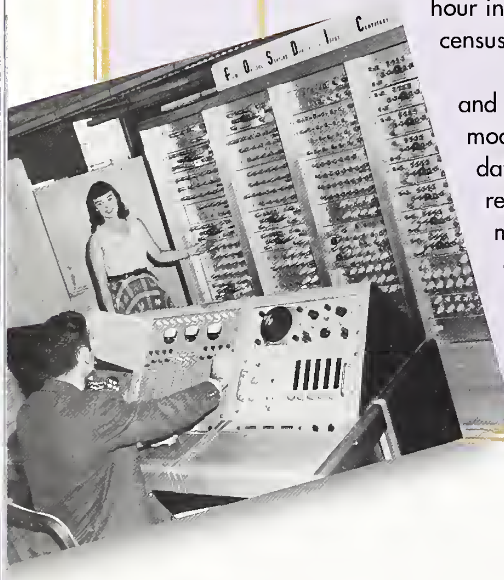
Automating the Census

Without realizing it, most Americans adults likely have had some of their household information scrutinized by FOSDIC.

The Film Optical Sensing Device for Input to Computers, which scanned microfilm of handmarked forms and converted the markings into electronic form, was developed by NIST for the U.S. Bureau of the Census in the early 1950s. Updated versions of the device processed data collected in the censuses held every 10 years from 1960 until 1990, introducing automation to this massive survey.

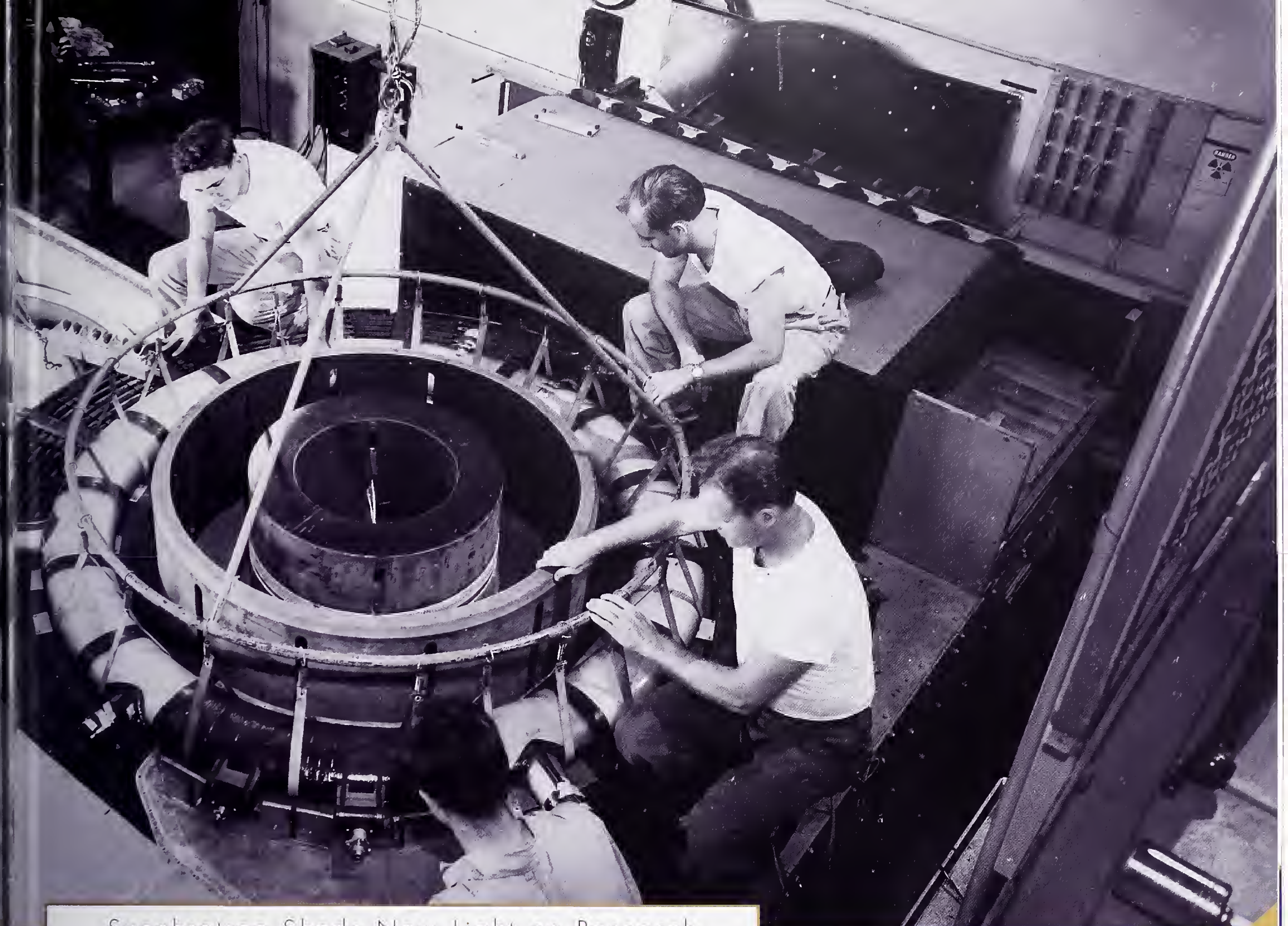
Before FOSDIC, census data were key-punched into cards. FOSDIC enabled the switch to multiple-choice documents and, by 1970, self-enumeration by the public, a cost-saving measure. Scanning with a cathode ray tube under the direction of a computer program, the first FOSDIC translated up to 10 million "answer positions" per hour into computer input. The last model used in the 1990 census operated at 20 times this rate.

Twelve different versions of FOSDIC were developed and put into service from 1954 through 1998. Various models were used by or for federal agencies to process data on fallout shelters, atmospheric pollutants, medical records, postal mail volume, and other surveys. The machines also were used to scan microfilms of archival weather data and special films made in underwater instruments. Among census-related applications, the machines collected data on which the nation's unemployment figures were based for more than 30 years.



Today's scientists compete for time on synchrotrons—large, donut-shaped facilities that produce a unique type of radiation. The technology is used, for example, to analyze protein structures as a basis for designing new drugs. But back in 1961, this research tool was little more than a curiosity outside of NIST, where the first regular experiments using synchrotron light were carried out.

Synchrotron radiation is emitted by electrons that are accelerated in a magnetic field. In the early 1950s, NIST found itself with an electron accelerator that another federal lab did not want. At the time, physicists were most interested in the particles



Synchrotron Sheds New Light on Research

(electrons) circulating in the device. It was also known that the electrons emitted light, which interested NIST because of the potential for an absolute radiometric standard—in effect, a "national standard light bulb." Among its advantages, the radiation is continuous across the spectrum and can be "tuned" to the desired wavelength.

Robert Madden, who became director of the Institute's Synchrotron Ultraviolet Radiation Facility (SURF), was hired in 1961 along with another spectroscopist, Keith Codling, to develop the NIST facility into a light source. Their groundbreaking studies of the energy-absorption spectrum of helium, and later other noble gases (neon, argon, krypton, and xenon), revealed new interaction mechanisms among the gases, radiation, and free electrons. The results startled scientists around the world and influenced the direction of atomic physics for some time. The research also affected fields such as astrophysics, where the new processes had to be taken into account in stellar models. Perhaps most importantly, Madden and Codling proved how useful synchrotron radiation could be.

An upgraded SURF remains in operation today, supporting work by the National Aeronautics and Space Administration and the microelectronics industry.

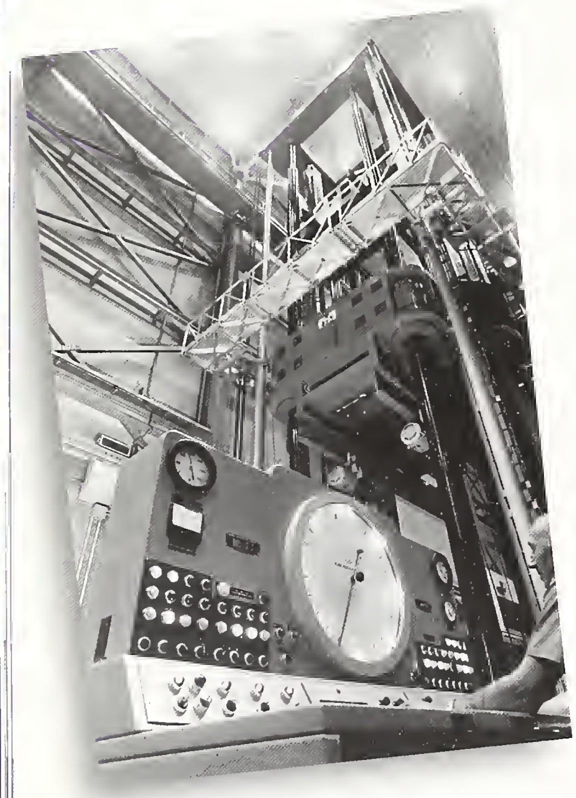
1961

already working on such problems as a result of the Army's first supersonic flight in the late 1940s.

Measurement capabilities were extended to new realms. In the 1950s, NIST could measure temperatures reliably only up to 3000 °C; by 1964, thanks to improved instruments and techniques, it was routinely measuring in the 20,000 °C range. To calibrate the devices used to measure the forces on large rockets, giant machines were built, such as a 4.5 meganewton (1 million pound) force machine that was 29.3 meters (96 feet) tall. The device to be calibrated was set at the top of a loading frame, and weights as heavy as 23 metric tons (50,000 pounds) were loaded in increments; the applied force was calculated from the mass of the weights. NIST still has the nation's largest universal testing machine, capable of supplying 53.4 MN (12 million pounds) of force in compression.

Meanwhile, the Institute continued to provide leadership in measurements and standards. The National Standard Reference Data System, centered at NIST, was established by law to provide critically evaluated quantitative data on the properties of chemical substances and materials important to science and technology. A key feature of the program was the independent assessment of the accuracy of data published in the scientific literature.

In 1960, the international scientific community adopted a new standard of length, replacing the old platinum-iridium meter bar with a wavelength of a specific frequency of visible light. (An Institute invention of the 1940s was influential in demonstrating the precision and practicality of a wavelength standard of length.) The new measure was based on atomic properties and could be reproduced with great accuracy, whereas the meter bar could be damaged or change over time. Shortly thereafter, NIST designed and built one of the first fully automated measuring machines, an interferometer (which used wavelengths of light as the unit of measure) for calibrating the intervals on



This universal testing machine has been used, for example, to test the performance of concrete columns under simulated earthquake conditions.

1964

Mathematics Handbook Becomes Best Seller

From making a military map to explaining the knock in gasoline engines or the light scattering that produces a rainbow, many technical and scientific challenges are best solved with the aid of mathematical functions. Such functions are so important that a national project devoted to compiling tables of them was established in the late 1930s. Thus began a NIST tradition of publishing mathematics reference data.

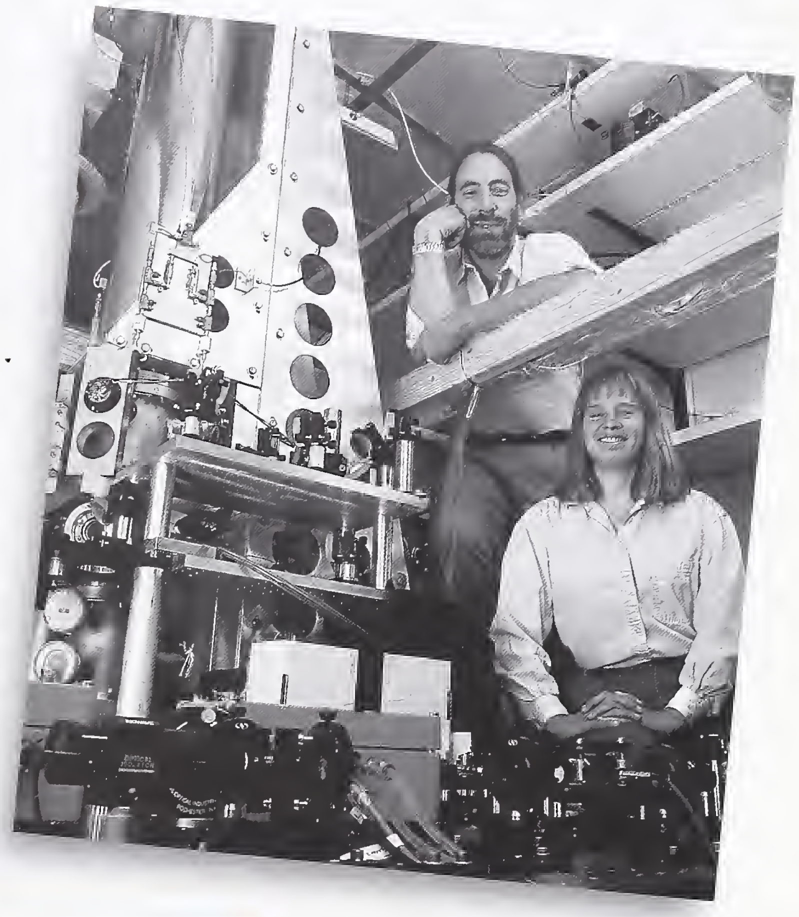
The invention of computers threatened to make the tables obsolete. But at a national conference in 1954, it was agreed that computers merely changed how the tables should be designed. For instance, for use in programming computers, the figures would need to be more accurate than before. So Milton Abramowitz and Irene A. Stegun of NIST produced an updated compendium, an effort that took eight years.

More than 1,000 pages long, the *Handbook of Mathematical Functions* was first published in 1964 and reprinted many times, with yet another reprint in 1999. Its influence on science and engineering is evidenced by its popularity. In fact, when *New Scientist* magazine recently asked some of the world's leading scientists what single book they would want if stranded on a desert island, one distinguished British physicist said he would take the *Handbook*.

The *Handbook* is likely the most widely distributed and most cited NIST technical publication of all time. Government sales exceed 150,000 copies, and an estimated three times as many have been reprinted and sold by commercial publishers since 1965. During the mid-1990s, the book was cited every 1.5 hours of each working day. And its influence will persist as it is currently being updated in digital format by NIST.

length scales. It reduced calibration time and cost by a factor of 10. Before the end of the decade, a new method of stabilizing lasers was discovered by NIST scientists, yielding a 1,000-fold improvement in reproducing measurements made with an interferometer.

The growth of science, military and space requirements, and the explosion in communications traffic demanded ever more accurate time standards, beyond that provided by NIST's original 1949 atomic clock. In 1960, a clock called NBS II, based on the natural frequency of the cesium atom, became the national standard of frequency, supplanting a set of quartz crystal oscillators. It measured frequency and time intervals to an accuracy of one second in 3,000 years. Since then, six even more accurate cesium-based clocks—the latest is accurate to one second in nearly 20 million years—have taken over as keepers of official national time, which is determined through a coordinated effort with the U.S. Naval Observatory. NIST shifted from an



NIST F-1, unveiled in December 1999, is one of the most accurate clocks in the world.

1966

An Early Spreadsheet

More than a decade before spreadsheet software helped to launch the boom in personal computers (PCs), NIST published Omnitab, a computer program for statistical and numerical analysis that had many attributes of a spreadsheet.

Conceived by the Institute's Joseph Hilsenrath and based in part on colleague Joseph Wegstein's earlier work on a tabular computing scheme, Omnitab was written to automate routine programming tasks—such as handling data input and output and producing graphs—for NIST physicists, chemists, and engineers, who were thus freed to concentrate on higher level science. Omnitab proved so helpful that its use extended far beyond NIST. For about 10 years after its 1966 publication, it was popular with statisticians in agricultural research, private industry, and universities. Foreign-language editions appeared as well; the program could accept simple commands in French, German, and even Japanese.

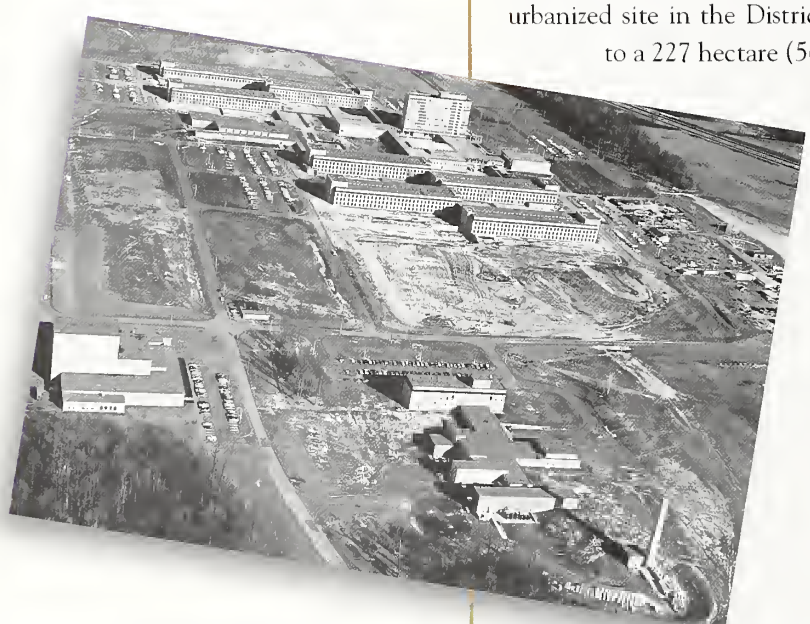
Omnitab was like a spreadsheet because it had an extensive and accurate math facility, a macro language, and a graphical output. Most importantly, it created a tableau in which the entries were calculated from input values. However, operations were defined for entire columns. VisiCalc, the "killer application" business spreadsheet unveiled in 1979 for PCs, allowed functions to be entered in individual cells and was more dynamic and interactive.

Omnitab initially used an old programming language and did not migrate to PCs until after its heyday. But its influence persists today in the form of Minitab, a PC-based commercial software package for teaching statistics and for research in business and manufacturing.

astronomical to an atomic definition of the second in 1967, when the international community defined the second as 9,192,631,770 oscillations of a particular type of cesium atom. To reconcile differences between the atomic time scale and the Earth's rotation, "leap seconds" are added from time to time.

The proliferation of computers also demanded standards. NIST issued the first Federal Information Processing Standard in 1968, a coded character set called the American Standard Code for Information Exchange, more commonly known as ASCII. All computers procured by the federal government after mid-1969 had to be capable of using ASCII, which was originally developed by an industry standards committee chaired by an Institute staff member. Advances in computing and modeling technologies also led to new tasks for NIST, which began performing systems analyses and operations research for other federal agencies. It studied transportation patterns, modeled patent activities, studied earthquake prediction, helped the U.S. Postal Service with mail handling and processing systems, and evaluated the performance of the hurricane warning center.

Institutionally, NIST matured. The main Institute campus moved from its aging, urbanized site in the District of Columbia to a 227 hectare (560 acre) former farm in



Aerial view of the NIST campus in Gaithersburg, Md., as facilities neared completion in 1965.

Learning from Structural Failures

By understanding the history of structural failures, NIST engineers and materials scientists help to make sure they aren't repeated.

So it was in 1967, when the Point Pleasant Bridge linking West Virginia to Ohio suddenly collapsed, dumping vehicles into the Ohio River and killing 46 people. Transportation officials asked NIST to send an investigator, and after he arrived, John Bennett found a shallow crack that appeared to initiate a fracture in a key piece of the bridge suspension system. This system was made of a relatively new carbon steel that, as was later learned, tended to crack. Many other cracks were found, all in areas of heavy corrosion.

The investigation underscored the importance of basic research in materials science and engineering. It also led to safer bridges nationwide. An identical bridge was closed in West Virginia, and federal highway officials then investigated cracks in all U.S. highway bridges.

Other high-profile failure analysis cases focused on ships and buildings. In the 1940s, a number of U.S. "Liberty" ships that had been welded together (instead of riveted) cracked apart when exposed to frigid water. NIST test results led to the use of better materials in supertankers.

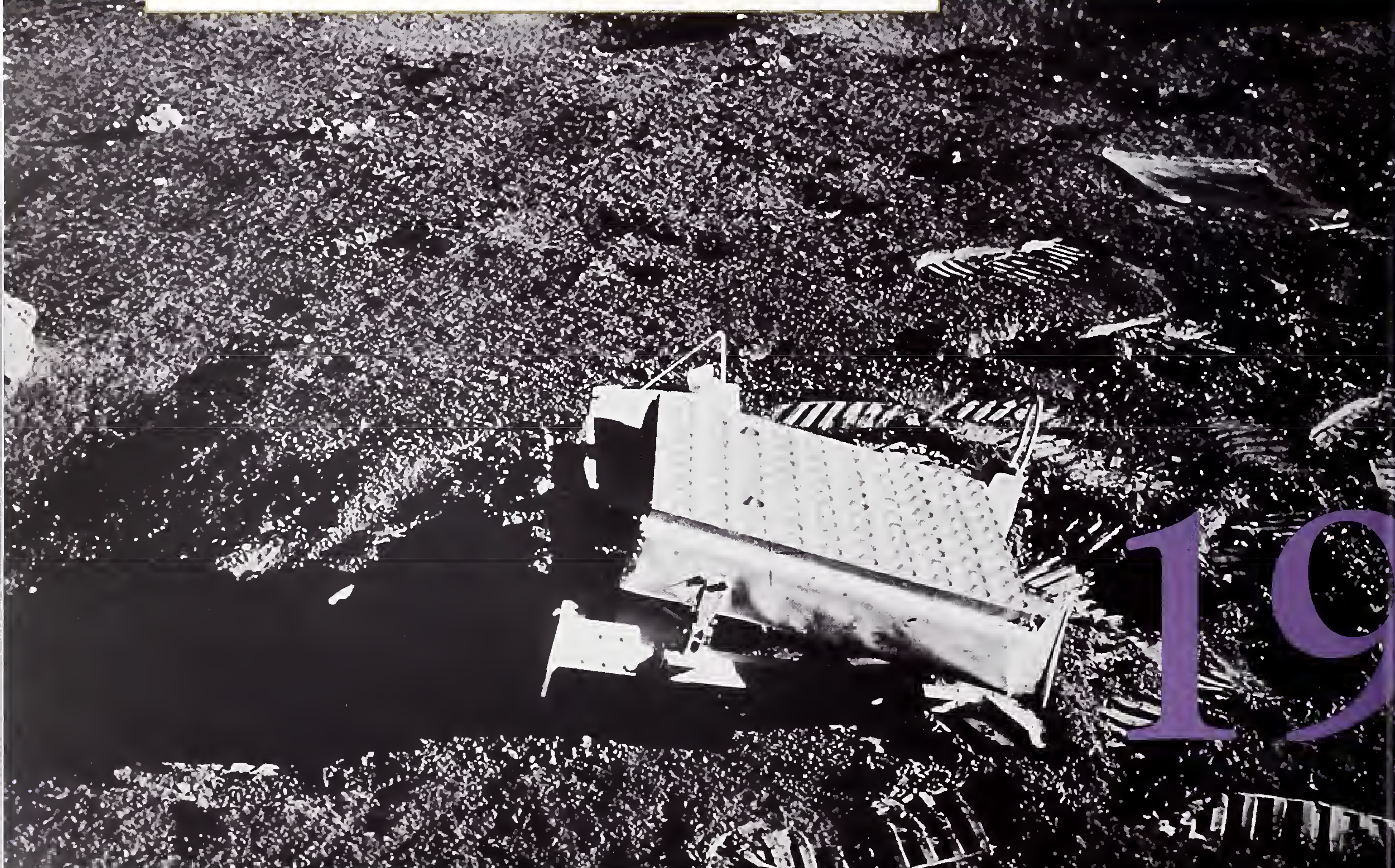
In 1981, NIST was asked to investigate the collapse of walkways in the Kansas City Hyatt Regency Hotel—the nation's worst building collapse, which killed 114 people and injured more than 200. (In photo at left, NIST researchers test a part from a Hyatt Regency Hotel walkway.) Among the major conclusions: Critical connections in two walkways were capable of supporting less than one-third of the load expected under the local building code. This condition resulted from a change by the fabricator in the original design, and subsequent approval of that change by the design engineer, without further analysis. As a result of this case, the American Society of Civil Engineers adopted a document assigning, for the first time, responsibility for various aspects of the construction process.

Gaithersburg, Md. Not long after the new site was dedicated in 1966, NIST's research reactor came on line. The reactor was, and continues to be, used for neutron standards, dosimetry, irradiation studies, and fundamental research. Another important addition, in Colorado, was the Joint Institute for Laboratory Astrophysics (later called JILA), which has been a model of interaction between government and academia. This cooperative effort of NIST and the University of Colorado went on to develop an international reputation in fields such as atomic physics (see Creating a New State of Matter, page 50).

NIST continued to perform research supporting industry. With U.S. highway fatalities exceeding 50,000 a year, the Institute also focused on auto safety. Working with the Society of Automotive Engineers, NIST prepared specifications for brake fluids and seat belts, either adopting or modifying existing standards. Through the use of a unique testing facility, a uniform quality grading system was developed for tire treadwear, traction, and temperature resistance. NIST also sought to improve the dynamic performance of the dummies used in crash testing. Once the fidelity of dummy tests was established, these tests were cited as justification for mandating shoulder harnesses in motor vehicles. Just as many other Institute efforts have been spun off to other agencies, this work eventually was transferred to the National Highway Traffic Safety Administration.

Important advances were made in materials science. NIST staff developed a reliable procedure for determining polymer melting points and proposed a new theory of polymer crystallization, both of which became mainstays of polymer science. In 1964, using the apparatus designed for one of NIST's most famous experiments (see parity experiment photo, page 24), a NIST/University of California group showed that superconductivity (the disappearance of resistance to the flow of an electrical current) could occur in an oxide

An Out-of-This-World Experiment



semiconductor, strontium titanate. This work foreshadowed Nobel Prize-winning research in the mid-1980s by two IBM Corp. researchers, who discovered an oxide material that was superconducting at much higher temperatures than was generally believed possible.

At least two major policy trends of the 1960s had long-lasting effects on NIST. First, a White House panel began encouraging the use of new technology in the civilian economy. The Department of Commerce was chosen to help spur economic growth, a formal mission that continues today: to find ways for government and science to interact in the realm of science and technology to stimulate economic prosperity. Second, the U.S. Congress became increasingly active with respect to environmental issues, passing laws and amendments recognizing various forms of pollution and requiring research and control efforts by both industry and government. ◆

1967

Assuring Quality in Tests and Materials

Before 1967, it was difficult to know whether a person really had high cholesterol. That's because U.S. cholesterol tests were off by as much as 23 percent—resulting in either unnecessary treatment or an increased (and unacknowledged) risk of death.

Things changed for the better after 1967, when NIST produced its first Standard Reference Material® (SRM®) for clinical applications. This pure, crystalline material, laboriously measured and analyzed, was used by manufacturers and clinical labs to calibrate instruments for analyzing cholesterol. By 1969, the uncertainty in cholesterol tests had fallen to 18 percent. It fell further to about 5 percent in 1995, thanks to new and improved renewals of blood serum SRMs for cholesterol values, as well as other factors.

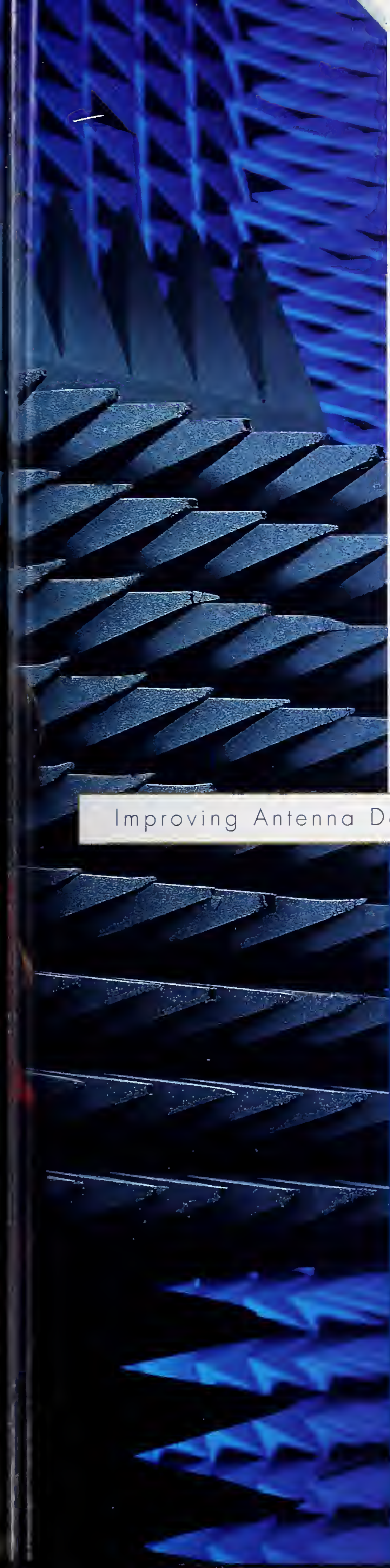
In recent decades, NIST has produced more than 60 different clinical chemistry standards, which help to assure the accuracy, reliability, and consistency of a wide variety of laboratory tests, from the amount of lead or glucose in blood to "DNA fingerprinting."

The clinical standards are just one category of SRMs, which date back to 1906 (when they were called standard samples). The program began when the Institute was asked to settle disputes regarding the carbon and sulfur contents of various irons and steels used by the railroad industry. At the time, virtually no technical information existed on the physical properties of these materials, and there were few standard test methods or calibrated measurement tools. NIST produced its first standard sample when the American Foundryman's Association requested standardized iron for its member industries. Today, some 35,000 units of SRMs are sold each year.

In their pioneering moon landing on July 20, 1969, the Apollo 11 crew left behind a briefcase-sized array of reflectors that bounce back a powerful laser pulse aimed at it from telescopes on Earth. By measuring the round-trip travel time for the pulse (about 2.5 seconds), scientists defined the distance between the Earth and moon to better than 2.5 cm (1 inch). The experiment—one of the space program's longest running and most cost effective—was suggested by James Faller of JILA, a Boulder, Colo., research institute jointly operated by NIST and the University of Colorado. He also provided the initial design for the Apollo 11 array and the two additional reflector arrays that were left by later missions, Apollo 14 (shown at left) and Apollo 15. The experiment, which is still active today, continues to provide new insights into the length of the Earth's day; knowledge of the moon's orbit, the lunar tides, and the combined mass of the Earth and moon; and an important test of gravitational theories.

69

Energy and Environment



Public support for science dwindled in the late 1960s and early 1970s, perhaps in part because of the financial drain of the Vietnam War and the growing perception that science could not cure many social problems. Scientists, therefore, had to become more active and skilled in convincing funding sources that their research was socially relevant and worthwhile.

Much of NIST's work during this time directly affected the public. At the behest of the Congress, for instance, the Institute undertook a comprehensive study of the metric system and published *A Metric America*, which recommended a policy of voluntary conversion. President Gerald Ford signed the policy into law in 1975; the U.S. government continues to encourage a voluntary changeover. NIST also prepared an impartial method for the draft lottery of July 1970, influencing which of America's young people would enter military service. Public safety was a driving concern: NIST helped investigate a number of major disasters, from a Texas tornado to a California earthquake, and provided technical support for the new Consumer Product Safety Commission, studying everything from the flammability of sleeping bags to children's capabilities to push, pull, and twist toys in harmful ways.

NIST also applied basic research knowledge to solve practical problems. Research in acoustics, begun years earlier, was applied to non-destructive methods for detecting flaws in materials and structures. In acoustic emissions technology, transient microscopic vibrations of a structure such as a highway bridge are monitored to anticipate the potential failure of critical components. To overcome the difficult challenge of detecting pulses that last only a microsecond, NIST reduced the problem to three essential elements, each of which was then solved. The staff developed a standard acoustic emission source that became widely used, a predictive analytic computer code for wave propagation in materials, and a

Improving Antenna Design and Performance

The 1,000 satellites orbiting the Earth today would be space junk without high-performance, cost-effective antennas to transmit and receive communications signals. Among NIST's pivotal contributions to antenna technology was the development of a theory that made it practical for researchers to compute an antenna's complex outdoor radiation pattern using data collected entirely indoors near a test antenna. (Photo at left shows an antenna being readied for near-field measurements.) NIST also developed software for using the data to compute field performance; the source code remains in use today. These advances have saved millions of dollars in testing costs for the military and satellite manufacturers, among other users.

1970

high-fidelity sensor that accurately measured emissions.

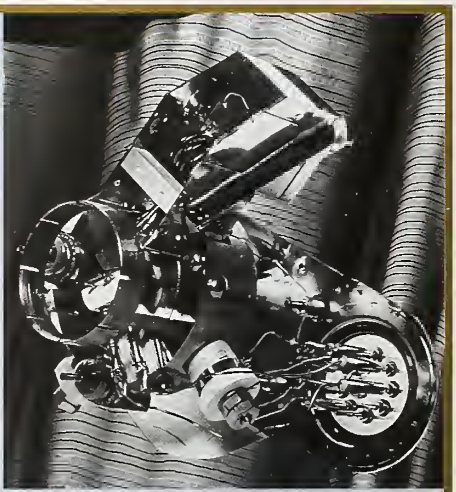
As always, NIST provided calibration services to hundreds of firms, not only doing the work but also showing others how to do it themselves. For instance, an Institute scientist showed a state metrologist how $500 worth of off-the-shelf equipment, coupled with radio signals from NIST radio station WWV, could be used to calibrate the tuning forks needed to check the accuracy of police radar equipment.

Meanwhile, basic research in fields such as physics and surface science enabled NIST to maintain and enhance the technical competence needed to carry out multiple missions and provide the measurement foundation for technological innovation.

NIST research in atomic physics centered around the use of laser light to cool and trap various particles. The first proposal for cooling atomic ions (atoms possessing a net electrical charge) was made in 1975 by scientists including one from NIST, who, concurrently with another team, reported the first successful demonstration of this effect in 1978. By the mid-1980s, two other Institute scientists demonstrated different techniques for cooling, or slowing, atoms (which are neutral and therefore pose different challenges), a prerequisite for trapping them. All of this work was motivated initially by fundamental

1971

A New Kind of Microscope



The scanning tunneling microscope (STM), widely used today in fields ranging from molecular biology to nanotechnology, enables scientists to see and manipulate individual atoms on surfaces and understand some of the physical, electronic, and magnetic structures of surfaces. It is such an important tool that, in 1986, two IBM Corp. scientists shared the Nobel Prize in physics for building the first STM able to glimpse the atomic surface. Today, there are about 5,000 STMs and related instruments in use throughout the world.

Some 15 years before, NIST physicist Russell Young built the Topografiner (see above), a novel microscope that surveyed surfaces in great detail, nearly to the level of individual atoms. With this instrument, Institute researchers demonstrated the operating principle of the STM. The Nobel committee credited Young with being the first to demonstrate the use of a sharp-tipped stylus, held at a very small and constant distance above a sample, to scan and map surfaces. The committee also recognized Young for proposing to use "tunneling" current—a quantum mechanical phenomenon—as the means to image surfaces. Today, the Topografiner resides in the Smithsonian Institution.

Young's work is a highlight of extensive NIST research on surfaces, sometimes described as a fourth state of matter because they are so different from solids, liquids, and gases. Rapid advances in surface science at NIST and elsewhere from the 1960s through the present have contributed to the development of catalysts, semiconductor devices, chemical sensors, and computing systems. In 1985, for example, Institute researchers demonstrated magnetic imaging using scanning electron microscopy with polarization analysis (SEMPA), a new type of microscopy they developed to observe magnetic structures up to 100 times smaller than can be seen using optical techniques. Since then, SEMPA has assisted in the rapid development of high-density magnetic data-storage systems.

scientific needs and drives, but, as noted at the time, it was easy to imagine that unforeseen uses might arise. Indeed, this research led to a Nobel Prize in physics for a NIST scientist and a variety of practical applications (see text box, page 54).

Much of NIST's time during this era was taken up with research on energy and environmental problems, largely in response to the oil embargo of 1973 and a batch of environmental legislation as well as growing public support for protection of the environment. The first Earth Day was held in 1970. Several years later, it was estimated that the United States would spend more than $190 billion over the next 10 years to attain federal standards for air and water quality. NIST was a key player in the environmental movement because pollutant concentrations had to be measured accurately.

The Origins of Closed Captioning

In an example of a research technology with significant commercial spin-offs, NIST's TvTime, a method for broadcasting time and frequency information on television, was transformed into closed captioning. Approved for wide use by the Federal Communications Commission in 1976, the technology won an Emmy Award for outstanding achievement in engineering development in 1980. It has greatly benefited the deaf and hard of hearing. Today, closed captioning is used on virtually all nationally broadcast programming, most new syndicated programming, many cable programs, and thousands of motion pictures. It also created a new industry of suppliers of closed captioning services.

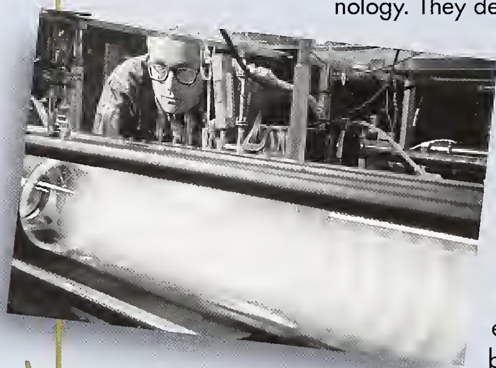
1971

Energy and Environment

1972

Making Better Measurements

Measurements have a symbiotic relationship with science and technology. They depend on each other, and if one advances, the other does too.



A case in point is the work of Ken Evenson and his team at NIST's Boulder campus, who made a world-record measurement of the frequency of laser light in 1972. That led to a much more accurate value for the speed of light, thus enabling scientists to better understand the behavior of the universe and more accurately track satellites and spaceships. The ripple effect of the advance then came back full circle to measurement science in the form of a new, more stable definition of the meter.

NIST actually achieved nine world-record measurements of laser frequency between 1969 and 1979. But the one in 1972 was special because the laser was stabilized, ensuring that any other similar laser will operate at the same frequency so that the experiment can be repeated. This design also enabled accurate independent measurements of the light's wavelength.

Wavelength multiplied by frequency equals the speed of light—which in this case was 100 times more accurate than the value accepted for the previous 15 years. The new value for the speed of light was accepted internationally in 1973 (and finalized in the 1983 redefinition of the meter).

Because frequency can be measured more accurately than wavelength (in fact, frequency is the most accurately measured value in science), scientists then wanted to improve the standard of length, which had been defined in terms of the wavelength of a certain type of light. In 1983, based largely on the achievements of Evenson and his team, the meter was formally redefined in terms of the new value for the speed of light.

1977

Safeguarding Electronic Data

About the time the personal computer was invented, NIST issued the first publicly available data encryption standard (DES)—a landmark event in an era when most cryptographic equipment was either proprietary or classified.

DES has secured much of the world's electronic data ever since. It was the first cryptographic algorithm endorsed by the federal government and was embraced by the private sector, especially banking, where it protects billions of dollars in transfers and other financial transactions daily. When a person withdraws cash from an automated teller machine, for instance, his or her personal identification number is probably encrypted using DES.

Reflecting the popularity of DES, four leading standards-setting organizations participated in the development of DES-based cryptographic standards for financial data, information processing and financial services, federal procurement, and telecommunications security. Commercial hardware and software products also rely on it. The most recent industry survey showed that, as of late 1997, almost half of U.S. cryptographic products and 43 percent of foreign products used DES.

The DES algorithm was developed by IBM Corp. However, NIST played a major role in the resulting popularity of the technology by making it a standard for federal agencies, assuring that the standard met all requirements and was acceptable to many potential users, analyzing security concerns, and evaluating the costs and benefits of modifying or replacing the standard. The thoroughness of the testing is reflected by the fact that, even 23 years after it was issued, DES is still considered unbreakable except by brute force (i.e., using computers to try every possible 56-bit key). Today, NIST is coordinating the development of a more powerful successor standard.

Among its energy conservation projects, NIST published design and evaluation criteria for new buildings. The publication served as the technical basis for industry's first major voluntary consensus standard for energy conservation in new buildings. A consultant's evaluation found that this new standard would reduce energy consumption by as much as 59 percent in some buildings. A study covering the time period 1975 to 1984 found that NIST's contribution to the energy cost savings in single-family houses due to the industry standard was $919 million in 1975 dollars ($2.6 billion in 1995 dollars)—many times more than the cost of the program. In a separate project, NIST developed testing and rating procedures for all major energy-consuming equipment in residential buildings to support the development of national efficiency standards by the U.S. Department of Energy.

Environmental research spanned air, water, soil, and living organisms. A portable meter was designed to detect a broad range of electromagnetic interference with twice the sensitivity of previous devices; it could be used to assess the emissions of appliances and maintain safe exposure levels for industrial workers. Various devices were developed to measure pollutants such as those from automobile emissions. A computer model was written to help allocate fish catches in a river system; the model provided a detailed analysis of the economic and biological effects of changes in the salmon fishery regulations.

In another area of enviromental concern, NIST introduced Standard Reference Materials to help gauge radioactive contamination of the environment, the first and still leading international effort of this type. NIST also created a biomonitoring specimen bank in cooperation with the U.S. Environmental Protection Agency. Thousands of specimens, ranging from marine mussels to human livers, were preserved in liquid nitrogen and then analyzed to measure changes in exposure to chemicals and pollutants over time. As the tissue banking activities expanded to encompass a broad range of environmental samples, Institute scientists established standard protocols and practices for proper handling of environmental samples. These procedures, as practiced by environmental labs around the world, help ensure the quality and reliability of environmental measures. ◆

A container of tissue samples is removed from storage in NIST's biomonitoring specimen bank, used for monitoring long-term pollution and health trends.

1979

In Semiconductors, Smaller Is Better

As integrated circuits (computer chips) shrink in size, the semiconductor industry needs increasingly tiny "rulers" for measuring the widths of circuit features. If feature size is not controlled, then the chips may fail. Who better to meet this need than NIST, which has assisted the semiconductor industry for more than 45 years?

When the feature-size issue first arose, NIST created an entirely new measurement system and, in 1979, issued its first photomask linewidth standard, which became an instant best seller. Three leading companies stopped using internal standards and adopted the one from NIST. This standard reduced measurement discrepancies among companies tenfold, stimulated the production of new commercial instruments, extended the range of use of optical microscopes, and saved the industry millions of dollars annually.

By the mid-1980s, chip features were on the order of 1 micrometer wide (75 to 100 times thinner than a human hair). Today, dimensions are about one-tenth that size. To meet today's needs, NIST has responded with photomask linewidth standards with ever smaller features, as well as several new approaches for accurately measuring circuit features as small as one-tenth of a micrometer (or less). Methods that use the spacing between crystalline silicon atoms or direct counting of the atoms as the ruler are currently being pursued. NIST researchers also are developing special microscopic techniques for use as calibration and metrology tools.

New Directions

Although the value of science and technology seemed unquestionable, federal agencies still needed to demonstrate the value they returned to taxpayers. This was particularly true as Americans began focusing, perhaps more than ever, on their economic prospects. The 1980s, after all, are often characterized as a time when Americans became preoccupied with money. And yet there was a collective uncertainty concerning how to explain economic growth and, in particular, how to sustain it. Thus, after decades of contributing to the national prosperity in myriad ways, NIST began efforts to formally demonstrate its influence.

In 1981, the first formal analysis of the economic impact of NIST programs was published. A consultant estimated that the semiconductor metrology program significantly boosted the industry's productivity in the mid-1970s, improving product features and reliability, increasing production yields, and reducing costs—and providing social returns that matched or exceeded levels reported elsewhere for privately generated innovations. The study estimated that the metrology program's research contributed $30 million to $50 million per year to the semiconductor industry in the mid-1970s. More than 20 other economic impact studies since have been carried out for NIST laboratory programs, revealing substantial returns on investment.

NIST also expanded its interactions with the private sector, building on a tradition of assisting and collaborating with trade associations, individual firms, and industrial consortia. Its program of hosting industrial research associates, begun in the 1920s, had more than 200 participants by the mid-1980s, for example. The rest of the federal laboratory system adopted a similar style of interaction during the 1980s, when new laws were passed emphasizing cooperative research and technology transfer. Many view this legislation as implementing the practices developed at NIST over the years. (By August 2000, NIST would report more than 950 cooperative research and development agreements over a 12-year period, as well as 1,550 visiting scientists on site annually.)

1982

Monitoring Enviromental Pollution

The environmental movement of the 1970s was sustained by many research projects at NIST, which developed standards and methods for measuring all sorts of pollutants in air, water, soil, and sediment. Many NIST innovations—such as an instrument that characterizes microscopic particles in the air and standards for measuring fuel economy and emissions—remain in use today.

NIST also served as an objective technical resource and trusted arbiter when asked by the Environmental Protection Agency (EPA) to help resolve one of the most contentious issues of the era—the extent of chemical contamination of the Love Canal area of Niagara Falls, N.Y. The EPA conducted an environmental monitoring program at Love Canal and asked NIST to review the draft analysis for organic chemicals.

NIST experts in organic analytical chemistry, quality assurance, and statistics reviewed certain aspects (although not the conclusions) of the draft. They found a number of significant deficiencies; among them, EPA's study design did not permit a comparison of contamination levels at Love Canal with those deemed hazardous or found in U.S. cities. But the Institute also determined that the analytical techniques were appropriate to the general goals of the study and represented the best overall techniques for monitoring organic chemicals in environmental samples. Ultimately, the EPA concluded that no significant amounts of contamination were found except in the immediate vicinity of the canal, in nearby storm sewers, and in the creeks near sewer outfalls.

Although the NIST report was critical of some aspects of the EPA study, which was released in 1982, an EPA administrator called it "the most thorough, extensive, state-of-the-art environmental study ever undertaken" and described NIST participation as "essential for the successful completion of the study."

Some scientists predicted that such a feat would be impossible. Others tried it and failed. But NIST succeeded in developing a standard for the volt that is more accurate, more stable, and much easier to use than its predecessors.

The NIST standard is absolute in the sense that it is based directly on a single, simple equation of physics and thus offers a major advantage over previous standards. It is based on the "Josephson effect," observed when two superconducting materials are separated by a thin insulating film and a current tunnels through the barrier (or junction). When such a device is irradiated with microwave radiation of known frequency, a voltage is induced across its terminals that is related to the frequency and two well-known fundamental atomic constants. The magnitude of the voltage can be calculated readily from the known frequency and constants.

It was not easy putting the Josephson effect to metrological use. A single junction produces a maximum output of a few millivolts, much less than the standard device then used by the Institute to represent 1 volt. (For years, the legal volt was maintained on the basis of the "mean electromotive force" of a bank of electrochemical cells, a value that drifted over time and between labs.) Then in 1970, NIST developed an instrument based on Josephson junctions that could generate a signal of 2 to 10 millivolts and compared it to the U.S. legal volt with acceptable accuracy.

The big breakthrough came in 1984, when NIST demonstrated the first practical array of Josephson junctions at the 1-volt level. (The photo below shows the standard undergoing testing.) Two years later, a 10-volt standard was developed. With almost 20,000 junctions, it was, for a time, the largest practical superconducting circuit in the world. Today, at least 40 national standards laboratories, military organizations, and private companies worldwide rely on standards based on NIST-developed technology to calibrate voltmeters. Products made with these instruments range from compact disk players to missile guidance systems.

1984

Defining the Volt, Absolutely

With U.S. firms facing growing competition in a global economy, NIST researchers found ways to improve on traditional manufacturing practices and materials. A robotic manufacturing system designed and assembled by NIST began operating at a naval shipyard in California, producing any of 40 different pipe connector parts used to suppress noise in nuclear submarines. Whereas it took 17 hours to make one part by hand, the workstation could machine the same part in less than 30 minutes. The Institute also began studying the properties and processing of materials as a basis for engineering new materials for products offering enhanced performance. NIST worked with auto manufacturers, for example, to find economical ways of making lightweight automobile frames out of reinforced plastics.

In continuing its original mission of cooperating with and supporting the private sector, NIST emphasized programs designed to assist emerging industries such as biotechnology, space science, and optical communications.

Biotechnology became a byword of the 1980s with the development of DNA fingerprinting for identification purposes and the advent of genetically engineered products. Accordingly, NIST, the University of Maryland, and Montgomery County, Md., formed the Center for Advanced Research in Biotechnology (CARB), designed to be a multidisciplinary center of protein engineering. Among their achievements, CARB scientists worked with industry to alter an enzyme found in common soil bacteria so that laundry detergent containing the enzyme could better tackle tough stains, overcoming a long-standing problem in that industry. Meanwhile, NIST began producing standards to ensure accuracy in forensic DNA analysis. This technology was one of dozens for which NIST scientists have won R&D 100 awards, given annually by *R&D Magazine* for the most technologically significant new products of the year.

Space science advanced after the first reusable spacecraft, the shuttle, was sent into orbit in 1981. NIST actually made the first sales of a product manufactured in space, in the form of a measurement tool. Billions of tiny polystyrene spheres, made highly uniform in shape and size in the low-gravity environment of space, were made available as a Standard Reference Material for calibrating instruments used by medical, environmental, and electronics researchers. Such instruments could be used, for example, to count and measure the shape of blood cells. Another project involved radiometric calibrations of an optical simulator and light sources for the Hubble Space Telescope, put into orbit in 1990. NIST was the only lab in the world that could provide certain types of calibrations essential for space-based astronomy.

To contribute to the development of standards for medical and surgical devices, NIST researchers studied materials used in artificial joints.

A krypton lamp similar to the one in the photo was calibrated with NIST's help for the Hubble Space Telescope.

Back on Earth, fiber-optic technology began to show up in U.S. communications systems because it could carry far more data than traditional copper telephone lines. NIST had anticipated this trend when its staff began characterizing optical fibers in the 1970s. These hair-thin strands of glass carry information in the form of light waves emitted by lasers. As fiber optics became more pervasive, the NIST program expanded to include measurement and calibration services and research on devices that send, receive, and process data. There was some urgency to this work because, although Americans invented the core components of optical technology, Japan had taken the lead in marketing products based on them.

By the mid to late 1980s, U.S. leaders were increasingly worried about foreign competition, principally from Japan but also from Europe. A deluge of government and industry reports warned that America was falling behind in key technology areas, succumbing particularly to Japan's ability to commercialize U.S. inventions first and manufacture products efficiently. One of the more timely examples was Japan's success in commercializing the video-cassette recorder, which had been invented years before by a U.S. company.

A key part of the federal government's solution to this problem was NIST, which had been reorganized and redirected several times in its history, but never so dramatically as in 1988, when the Omnibus Trade and Competitiveness Act was passed.

The purpose of the act was "to modernize and restructure [NIST] to augment its unique ability to enhance the competitiveness of American industry while maintaining its traditional function as lead laboratory for providing the measurements, cali-

1984

Discovering a New Material

When a peculiar arrangement of metallic particles first appeared under an electron microscope at NIST, scientists thought it was a mistake. It was unlike any of the 230 crystal shapes described in reference books. But the pattern turned out to be a true reflection of the structure of a "quasicrystal"—an entirely new material.

The discovery of quasicrystals by NIST guest researcher Dan Shechtman (one of hundreds of guest researchers who collaborate with NIST scientists and use the facilities every year) was reported in 1984 by a team that included Institute scientist John Cahn, who subsequently developed models that enhanced understanding of the crystallography of these materials. The 1984 paper was cited 2,330 times in other publications by 1998, evidence of its wide influence.

Although initially skepticism was rampant, and alternate models of the structure were proposed for several years, quasicrystals eventually rewrote the rules of crystallography and spawned a flurry of activity in materials science, physics, and mathematics. Cahn later won the National Medal of Science, the nation's highest scientific honor, for his lifetime contributions to the fields of materials science, solid-state physics, chemistry, and mathematics.

The breakthrough was "pure serendipity," in Cahn's words, an unexpected boon of NIST research on the thermodynamics of rapidly solidified alloys. The researchers intended to cool a molten metal so fast that it would not crystallize in the usual manner. To their surprise, the aluminum and manganese atoms formed orderly structures that, unlike ordinary crystals, did not repeat at fixed intervals.

More than just an academic research topic, quasicrystals have practical uses because they are hard, lightweight, low friction, non-stick, non-scratch, and inexpensive. By the late 1990s, they were being commercialized as coatings for kitchen cookware and hardening agents for steel medical instruments. Many other uses are expected.

1989

Saving the Ozone Layer

The Earth is better protected from the sun today thanks to NIST research and data programs, which have helped to both define and solve the problem of chemical damage to the protective ozone layer.

Fundamental research by NIST in the 1970s underlined the damage caused by chlorofluorocarbons (CFCs) from aerosol propellants and refrigerants. NIST and the National Oceanic and Atmospheric Administration used laser spectroscopic techniques developed at NIST to identify and measure critical chemical reactions and then input the results into a computer model of the upper atmosphere. Because of this research, damage to the ozone layer from fluorocarbons was estimated to be three times greater than previously assumed.

With more than 50 years experience in providing industry with data on the physical properties of refrigerants, the Institute responded to an international agreement to phase out ozone-depleting compounds by launching a major effort to identify and characterize alternatives to CFCs. In 1989, NIST introduced REFPROP, a standard reference database of the thermophysical properties of alternative refrigerants. The Air Conditioning and Refrigeration Institute and the Electric Power Research Institute adopted REFPROP as the source of critically evaluated data for their alternative refrigerants evaluation program. The database, which has saved industry millions of dollars, is a prime example of how NIST and industry work together to successfully meet needs for reliable technical data.

Today, CFCs are being replaced by newer, less damaging refrigerants. REFPROP has proven especially valuable in the evaluation of refrigerant blends, such as those now used in some home air-conditioning systems and heat pumps. NIST has distributed widely used software that models important engineering aspects of the use of new refrigerant blends. In addition, Institute refrigerant data were used to validate the choice of an alternative refrigerant used in a wide variety of refrigeration and air-conditioning systems, including those in newer cars.

Scientists studied the optical characteristics of fluorescent molecules as part of NIST's research on biosensors.

NIST worked with industry to evaluate the performance of atmospherically safe refrigerants in refrigeration systems.

brations, and quality assurance techniques which underpin U.S. commerce, technological progress, improved product reliability and manufacturing processes, and public safety."

To go along with the expanded mission, its name was changed from National Bureau of Standards to the National Institute of Standards and Technology, and two new programs were added. The Advanced Technology Program (ATP) was designed to encourage private investments in innovative technologies with the potential for broad national benefit that otherwise would not be developed in time to be competitive in world markets. The Manufacturing Extension Partnership (MEP) was initiated to assist the 385,000 small U.S. manufacturers with a wide range of activities through a nationwide network of not-for-profit centers. These two efforts complemented the Baldrige National Quality Program, created in 1987 to manage the Malcolm Baldrige National Quality Award, which recognizes individual U.S. organizations for their achievement, and to promote quality awareness and provide information on successful performance strategies. ◆

Lasers were used to measure the response speed of optical communications devices.

Realizing the Future of Automation

They may not be taking over the world—at least not yet—but robots are getting smarter. And a growing number owe their "brainpower" to NIST.

In 1991, a floor-cleaning robot became the first commercial "intelligent machine" influenced by NIST's real-time control system (RCS), a concept for controlling automation developed by NIST's Jim Albus, a leading robotics researcher. The RCS has a unique hierarchical structure that creates an efficient organization for knowledge-based intelligent control of complex systems. Other commercial machines based on this concept are improving the precision of shipbuilding, delivering hospital supplies efficiently, and keeping U.S. troops out of harm's way by clearing land mines in Bosnia.

The RCS was among the influential technologies to emerge from NIST's Automated Manufacturing Research Facility (shown in photo above), created in 1982 to provide a national testbed for R&D in computer-integrated manufacturing. The facility, which was co-sponsored by the U.S. Navy and involved research collaborations with industry and universities, has led to dozens of commercial products and many national and international standards.

Among the contributions is the Standard for the Exchange of Product Model Data (STEP), which is designed to overcome interoperability problems that arise when automated systems attempt to share product and engineering data. These problems cost the auto industry alone about $1 billion annually. First released in 1994, STEP is a universal file format that supports computer-to-computer exchanges of all types of product data. Significant cost and process improvements have been reported by users.

1991

Technology proved its value to national security once again in the 1990s when the United States used it to help win the Gulf War. More significantly, technology also demonstrated its power to fuel economic growth when American inventions, such as the Internet and the graphical "browser" for the World Wide Web, created a new national pastime and a multitude of new information industries. Partly as a result of this phenomenon, the concerns of the 1980s regarding U.S. competitiveness dissipated somewhat. NIST contributed to the new Information Age in important ways by, for example, leading the development of standards for computer security, many of which subsequently were adopted as voluntary industry standards.

Development of civilian technology was accelerated in the 1990s through a series of government initiatives. With leading economists asserting that technology

1991

Neutrons Offer New Insights

From checking on food safety to nailing crime suspects to probing biological membranes, the NIST Center for Neutron Research (NCNR) has done practically everything a scientific facility can do—including some things that would be impossible anywhere else.

The center offers a broad array of instruments and capabilities, some of which are unique in the United States and even the world. A special set of rare tools was added in 1991, when the Cold Neutron Research Facility was completed and became the first U.S. facility devoted solely to research with cold (lower-energy) neutrons.

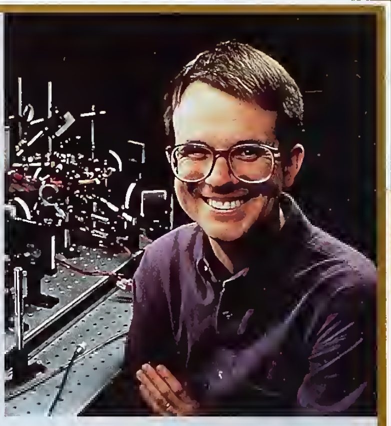
Neutron beams interact with the inner structures and dynamics of virtually any material, often revealing details that cannot be discerned in any other way. In its early years in the 1970s, the NCNR perhaps was best known for the use of "warm" neutrons in forensic investigations, such as the time when postal authorities matched specks of paint from a burglar's tool satchel with the paint at several post offices and broke up a burglary ring.

Today, the center is pushing the frontiers of many fields of science. For example, research with "cold" neutrons has revealed molecular mechanisms involved in regulating muscle contraction and led to the development of improved additives that enable diesel fuel to remain fluid at subzero temperatures. Depth-profiling techniques led to the creation of a titanium nitride Standard Reference Material that now is used in semiconductor testing, meeting one of that industry's greatest needs. Magnetic measurements have helped to explain the origin of the behavior of materials exhibiting "giant magnetoresistance," the basis for ultrahigh-density computer hard drives.

NIST is identifying biomarkers and developing standards and other measurement technologies needed to help ensure the safety and viability of tissue engineered materials.

1995

Creating a New State of Matter



Pushing the limits of technology is NIST's forte. It paid off in a big way in 1995, when scientists at JILA, a joint program of NIST and the University of Colorado (CU), created an entirely new state of matter predicted decades ago by Albert Einstein and Indian physicist Satyendra Nath Bose.

The Bose-Einstein condensate—widely hailed as one of the century's major achievements in physics—is an atomic counterpart to the laser in that a large number of atoms are in the same quantum mechanical state. (Lasers cause a large number of photons to have identical energy and direction.)

To make this new state of matter, NIST's Eric Cornell (pictured above) and CU's Carl Wieman cooled rubidium atoms to less than 1 millionth of a degree above absolute zero (the hypothetical point at which a substance would have minimal energy), as much as 300 times lower than ever achieved in other scientific laboratories. At a certain temperature, the atoms condensed into a "superatom" that behaved as a single entity.

The achievement was made possible by laser cooling and magnetic traps, technologies that NIST played a major role in developing. Infrared lasers, similar to those used in compact disk players, were aligned so that the atoms were bombarded by a steady stream of photons from different directions. Once the atoms were slowed and cooled, they were kept in place by a magnetic field and further cooled until the condensate formed.

1996

Biotechnology for the 21st Century

A device the size of a keychain launched an industry—and giant strides in science and medicine—in 1996, when it became the first commercial "DNA chip."

It did so with the help of NIST's Advanced Technology Program (ATP), which accelerates the development of innovative technologies for broad national benefit through R&D partnerships with the private sector.

The DNA chip is so named because of its similarity to the tiny integrated circuit that fuels the electronics industry. The difference is in the application. The newfangled device enables the operation of a miniaturized biological laboratory that quickly analyzes the genetic makeup of blood or tissue samples.

ATP funding also has led to other next-generation products for DNA analysis that have appeared on the market or in research laboratories, greatly advancing capabilities for research on human genetics, discovery of new drugs, improvements in agriculture, and testing of food and cosmetics. The new technologies are already up to 1,000 times faster than conventional methods, thereby saving time and money. They also are highly accurate and convenient.

As noted in a recent journal article, the "godfather" of the burgeoning field of DNA diagnostics is the ATP, which helped companies advance their early research to a stage where commercialization (with other funding) would be feasible. The ATP has co-funded more than two dozen projects in DNA diagnostics, including one that led to the first DNA chip, and a number of the award recipients are leaders in the field today.

accounts for at least half of U.S. economic growth, the federal government took a new approach to funding science and technology. Instead of just basic research and military and space applications, the new outlook also encompassed broadly applicable, "precompetitive" (not quite ready for commercialization) technologies that can be applied by industry to create better products, high-paying jobs, and a clean environment.

In addition to electronics and information systems, a number of other technology areas were identified by the government as critical or strategic to U.S. interests. These included energy and environmental quality, manufacturing, medicine and biotechnology, materials, and transportation. There remains strong interest in helping small businesses compete and in nurturing the

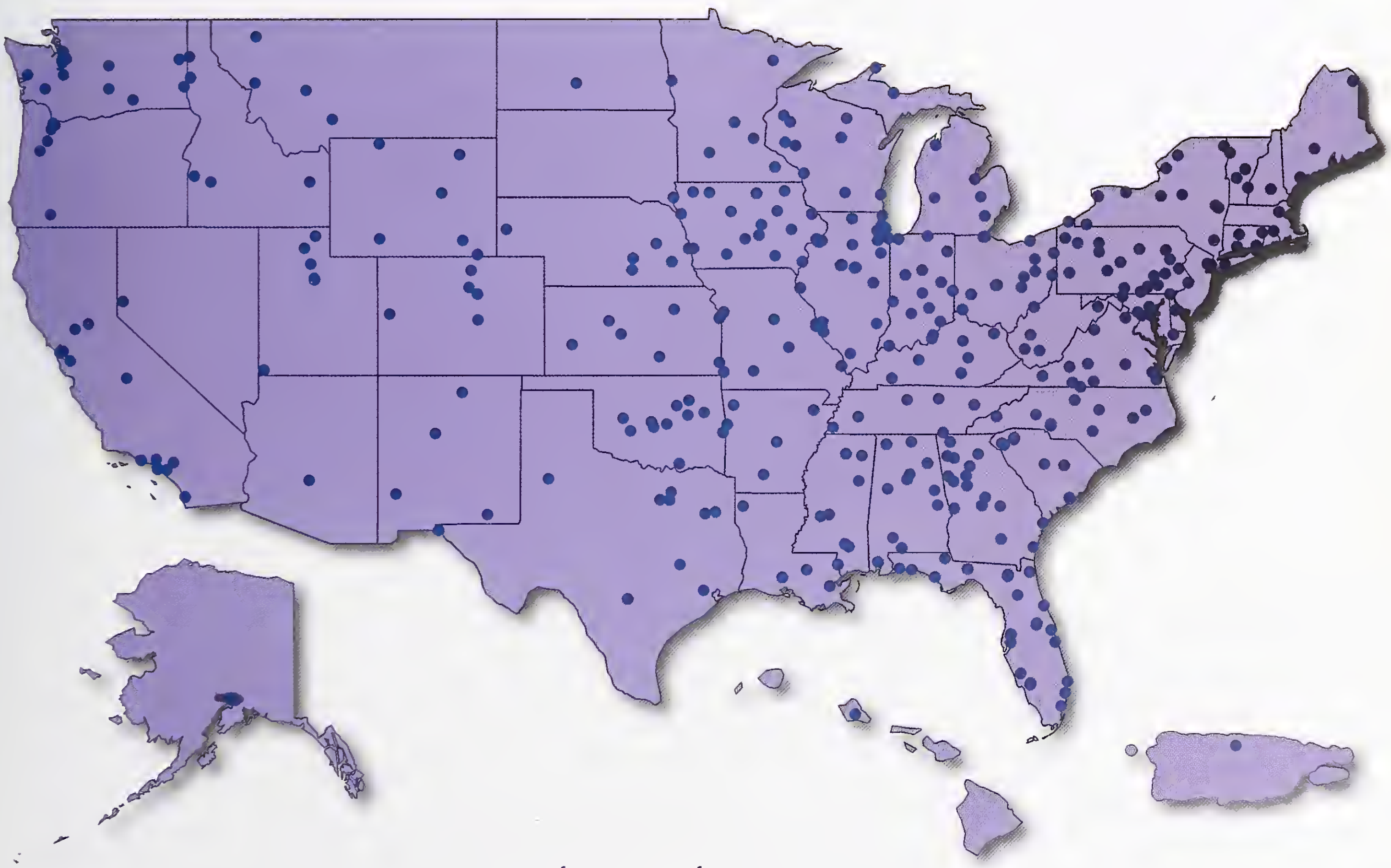
1996

Helping Small Manufacturers Thrive

Small manufacturing firms gained an important advantage in the 1990s in the form of NIST's Manufacturing Extension Partnership (MEP), which, according to an independent study, boosts the competitiveness of its clients beyond the average for companies of this size.

The MEP helps these firms with everything from financial planning to plant layout to environmental studies. The services are offered through a network of more than 400 not-for-profit centers that provide small and medium-sized companies with access to more than 2,000 manufacturing and business specialists. In 1996, the MEP reached its goal of completing a nationwide network, enabling all of the more than 385,000 U.S. small manufacturers in the 50 states and Puerto Rico to gain access to MEP assistance centers.

Through 1998, more than 84,000 firms have taken advantage of the services, which are fostering significant improvements in manufacturing and business performance. For example, in a 1999 follow-up study, 4,551 MEP clients reported increased revenues of $294 million, $29 million in labor and materials savings, and $20 million in inventory reductions, while also investing $291 million in modernization. These clients also reported creating and retaining more than 7,000 jobs.



As part of NIST's Manufacturing Extension Partnership, more than 400 not-for-profit centers offer smaller manufacturers technical and business assistance. Call 1-800-MEP-4MFG for the center serving your region.

1997

Fire Research Helps Save Lives

Three decades ago, U.S. fire losses were so large that a presidential commission was appointed to study the problem. The commission's 1973 report urged a greater emphasis on fire research, prevention, and education and set a national goal of reducing fire-related losses by at least 50 percent.

A 50 percent reduction in the U.S. fire death rate was attained in 1997. A primary reason: Smoke detectors now are installed in more than 95 percent of U.S. homes, compared to fewer than 10 percent in the early 1970s. NIST researchers made this improvement possible beginning in 1974 by developing, with Underwriters Laboratories' participation, the first fire performance standard for smoke detectors and recommendations on the number, type, and location of home smoke alarms now found in all U.S. (and most foreign) codes and standards.

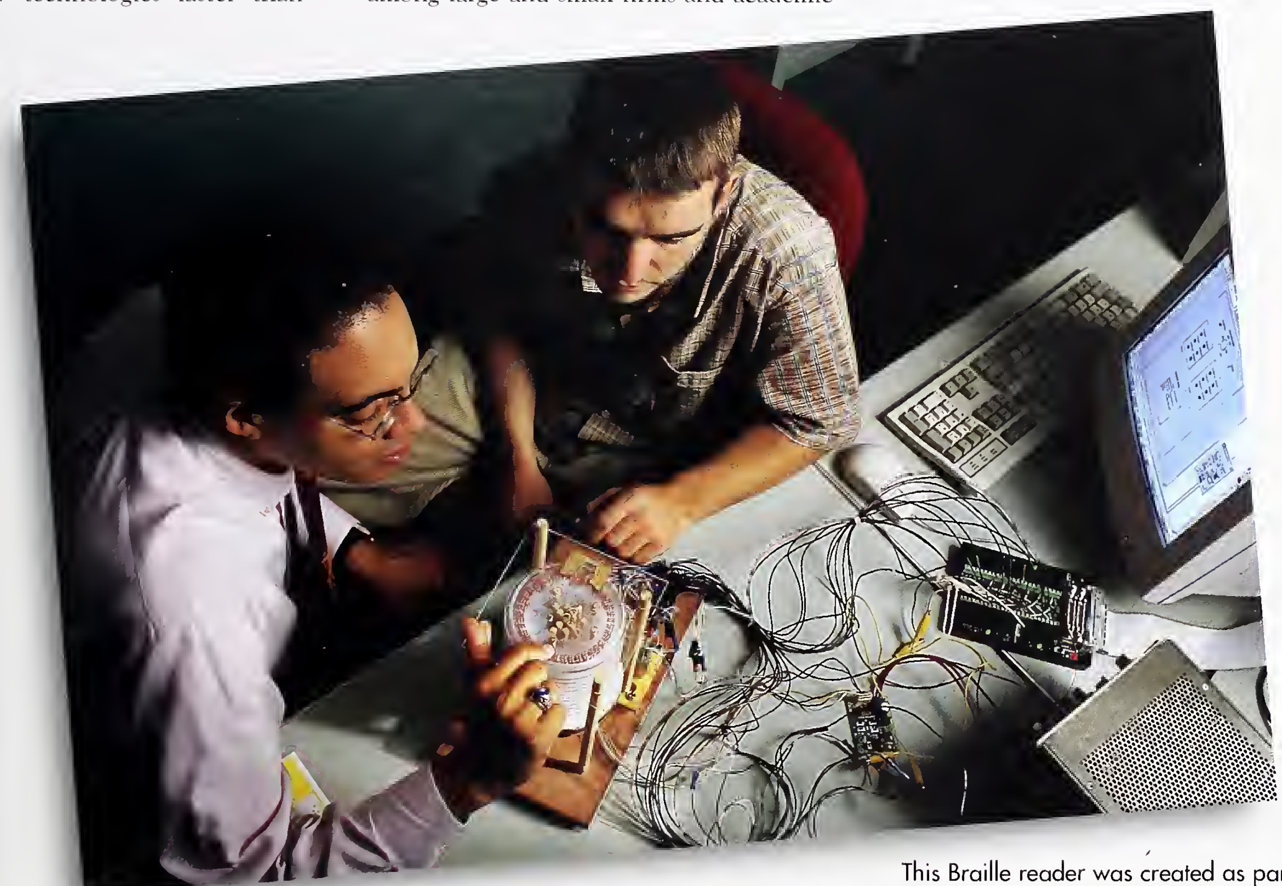
NIST also worked closely with other government agencies, performing the technical work underpinning the first federal standards on children's sleepwear and mattresses and writing the U.S. Fire Administration's most popular educational booklets. Fire fatalities attributed to children's sleepwear have virtually disappeared, and those from mattress fires have been cut in half. For the Federal Railroad Administration, NIST also tested the fire safety of passenger train seats (see photo below).

The Institute's long-standing relationships with the private sector have helped to introduce less-flammable floor coverings into the marketplace; verified the value of fire-retardant additives in increasing escape time from fires; and produced the only validated method for quantifying the lethality of smoke, now routinely used in fire hazard analysis.

interdisciplinary research that increasingly fuels advances in science and technology.

NIST continues to be involved in all these areas. In addition to maintaining strong basic research programs in physics, chemistry, materials, electronics, manufacturing, building technology, and other fields, its Measurement and Standards Laboratories provide measurements, standards, and other support for industries that produce critical technologies. This work helps companies solve problems and commercialize new technologies faster than before, a linchpin of competitiveness in the 1990s and the new millennium.

Meanwhile, the ATP nurtures innovation across a broad range of technology sectors. A study of the first 38 completed ATP projects estimated that the national economic benefits of just several projects will exceed the ATP's entire investment in the more than 450 projects selected at the time of the study. The ATP also has proven to be highly effective in fostering cross-cutting, interdisciplinary collaborations among large and small firms and academic

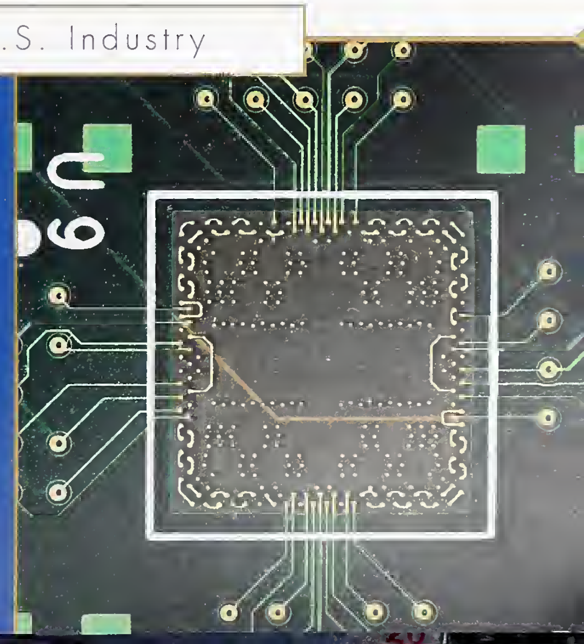


This Braille reader was created as part of a NIST project to make electronic books more accessible to the blind.

Turning Around a Key U.S. Industry

In 1991, the U.S. printed wiring board industry was in trouble. The $7 billion industry with its 200,000 jobs was saved, according to the president of the National Center for Manufacturing Sciences, by a research project co-funded by NIST's Advanced Technology Program. According to a 1997 study, the joint venture led to dramatic efficiencies in research and development (a $35.5 million savings, or more than two and a half times the ATP investment), accelerated research, and produced significant technological advances. The project also enabled more than 30 research tasks that otherwise would not have been attempted.

1997



1997

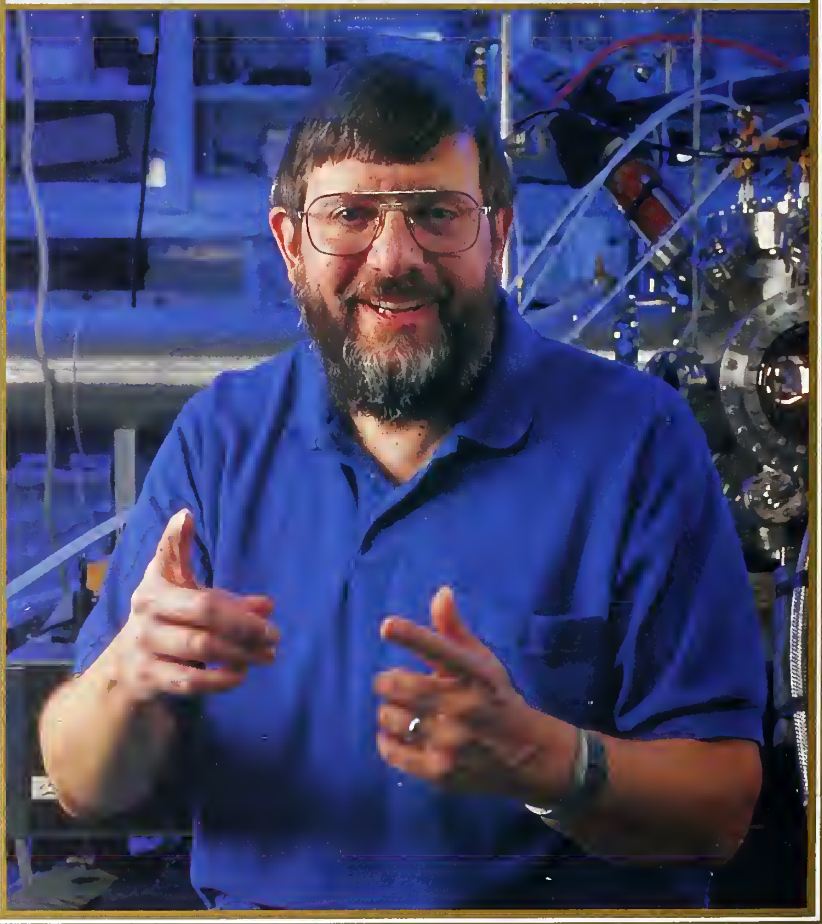
Laser Cooling and Trapping Win Nobel Prize

Atoms or molecules in a gas are difficult to study because they move so fast. The molecules in air, for example, move at about 300 meters per second, or 1,000 kilometers per hour. But by pushing on the gaseous atoms with laser light, scientists can slow the atoms down, cooling them to within a millionth of a degree of absolute zero. NIST physicist William D. Phillips (pictured below) won the Nobel Prize in physics in 1997 for his work on the development of methods to cool and trap atoms with laser light.

The discipline of cooling and trapping atoms, which emerged with the advent of laboratory lasers, was established in part by experiments with ions (electrically charged atoms) by David J. Wineland and others at NIST's Boulder campus beginning in the 1970s. Inspired by this work, Phillips and his team demonstrated both the trapping of atoms (which are electrically neutral) with a magnetic field and the cooling of atoms well below the temperature limits generally believed possible.

The Nobel committee said the new methods of investigation developed by Phillips and two other 1997 prize winners "have contributed greatly to increasing our knowledge of the interplay between radiation and matter. In particular, they have opened the way to a deeper understanding of the quantum-physical behavior of gases at low temperatures."

The research has enabled the design and construction of one of the world's most accurate clocks, NIST F-1, which is used by NIST (in cooperation with the Naval Observatory) to maintain the nation's time standard. In other experiments at NIST, laser cooling and trapping have been used to achieve a new state of matter. Some day, this research may lead to practical advances such as quantum computers capable of processing information in unique ways.



institutions. To assist small businesses, the MEP provides essential support and services, such as help in streamlining manufacturing processes to improve productivity. And a broad consensus has emerged indicating the Baldrige program has greatly improved attention to quality and organizational excellence across the private sector.

Although the economic threat posed by foreign countries has lessened for now, ensuring the nation's ability to compete in the 21st century remains a challenge. Recent analyses by a variety of organizations indicate that the U.S. lead over Japan is widening in technology areas such as software, sensors, and information management. But Japan is leading in other sectors, such as flat-panel displays, and gaining ground in others. And Japan has been joined by many other emerging economies. Of further concern, U.S. investment in

Flawed Rivets May Have Sunk *Titanic*

Since the sinking of the giant ocean liner *Titanic* in 1912, numerous theories have been advanced about the causes. NIST has one too—weak rivets. NIST metallurgist Tim Foecke's microscopic analysis of 48 wrought iron rivets recovered from the ship's hull have revealed that nearly 40 percent contained up to three times the amount of slag (the glassy residue left behind after the smelting of ore) allowed at the time. This made the rivets prone to premature failure. *Titanic*'s collision with the iceberg may have caused the rivet heads to break off, opening seams and allowing water to rush in between the separated hull plates, speeding the ship's descent.

1998

research and development is lower as a percentage of national wealth than it was in the early 1980s, leading some to question America's capacity for future innovation.

At the close of the 20th century, there are more than 700 federal laboratories in the United States, a stark contrast to the days when NIST stood alone in focusing on physical science. But NIST's influence continues to be pervasive. In fact, NIST's importance increases with the number of other federal laboratories (and university and corporate research organizations) because many of their measurements need to be traceable to NIST, and because technological innovation and development depend more on measurements now than at any time in the past.

Although the time has passed when U.S. technology standards automatically became de facto world standards, NIST staff continue to work toward ensuring the marketability of U.S. products worldwide by serving on more than 800 standards committees of national and international organizations. NIST also continues to explore the frontiers of science and industry, from atomic physics to electronic books, and the technologies of tomorrow, such as devices designed and fabricated on the nanometer scale that offer stunning new capabilities. Because who knows what tomorrow's equivalent of radio, atomic clocks, lasers, or the Internet will be ... or from where they will come? ◆

Promoting Quality in U.S. Firms

Is the quality of American goods and services getting better? Yes, according to the non-profit Council on Competitiveness. The council credits the Malcolm Baldrige National Quality Award as a key mechanism in strengthening U.S. competitiveness.

The Baldrige Award was established by the U.S. Congress in 1987 to recognize individual U.S. companies for their achievements and to provide quality awareness and information on successful performance and competitiveness strategies. Since then, the award, managed by NIST's Baldrige National Quality Program (BNQP) in conjunction with the private sector, has become the nation's premier award for business performance excellence and quality achievement. Since 1988, 37 organizations have received a Baldrige award.

More than 1.7 million paper copies of the BNQP Criteria for Performance Excellence—which has been called "the single most influential document in the modern history of American business"—have been distributed, reflecting the impact of the program. (Additional copies are available in books, from state and local award programs, and for download from the World Wide Web.) The criteria span company leadership, strategic planning, customer and market focus, information and analysis, human resource focus, process management, and business results. Also in 1999, the program was expanded to include educational organizations and health care providers, promising important benefits to consumers.

State and local quality programs—most modeled after the BNQP—have increased in number from fewer than 10 in 1991 to more than 50 in 1999. Forty-three states currently have programs. Internationally, nearly 60 quality programs are in operation, most modeled after the Baldrige program, including one in Japan.

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