NISTIR 5133

U.S. DEPARTMENT OF COMMERCE
TECHNOLOGY ADMINISTRATION
National Institute of
Standards and Technology

PHYSICS LABORATORY

Technical Activities 1992

Submitted to the
Board on Assessment of
NIST Programs,
National Research Council
May 3-4, 1993

NIST

DESCRIPTION OF COVER ILLUSTRATION

Internal Components of NIST-7. Internal components for NIST's new optically-pumped-cesium frequency standard are shown in the picture. One end of the copper microwave cavity with a small hole for the cesium beam can be seen in the center of the picture. A movable-aperture mechanism for changing the beam collimation is at the right of the cavity. In normal operation this mechanism is placed in front of the cavity. The spherical mirror at the bottom left is part of the light collection optics used in optical-state detection of atoms that have traversed the microwave field.

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Katharine B. Gebbie, Director
William R. Ott, Deputy Director
Physics Laboratory

March 1993

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Institute of Standards and Technology
Raymond G. Kammer, Acting Director

ABSTRACT

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during calendar year 1992 in the NIST Physics Laboratory. These activities fall in the areas of electron and optical physics, atomic physics, molecular physics, radiometric physics, quantum metrology, ionizing radiation, time and frequency, quantum physics, and fundamental constants.

Key Words: atomic physics; calibrations; data evaluation; electron physics; fundamental constants; ionizing radiation; measurement methods; molecular physics; optical physics, optical radiation; quantum metrology; quantum physics; standard reference materials, time and frequency

Printed Pages: 213

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Certain commercial equipment, instruments, or materials are identified in this report in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

PHYSICS LABORATORY

INTRODUCTION

This report is a summary of the technical activities of the National Institute of Standards and Technology (NIST) Physics Laboratory for the period January 1992 to December 1992. The Laboratory is one of nine major operating units of the National Institute of Standards and Technology. The mission of the Physics Laboratory is to advance science and technology by: pursuing fundamental research in the physical sciences; developing new physical standards, measurement methods, and data; conducting an aggressive dissemination program; and collaborating with industry to commercialize our inventions and discoveries.

The Laboratory is vertically integrated, spanning the full range of programs from tests of fundamental postulates of physics through generic technology to the more immediate needs of industry and commerce. Its constituencies are broadly distributed throughout academia, government, and industry.

The Physics Laboratory focuses its long-term research on atomic, molecular, optical, and radiation physics. It develops new physical standards, measurement methods and reference data, and promulgates these standards, methods, and data by providing measurement services, conducting workshops, publishing research results, and collaborating with industry, universities, and other agencies of government.

Specifically, the Laboratory establishes spectroscopic methods and standards for infrared, visible, ultraviolet, x-ray, and gamma-ray radiation; investigates the structure and dynamics of atoms and molecules, singly and in aggregate; develops and disseminates national standards for time and frequency and for the measurement of optical and ionizing radiation by means of calibrations, measurement quality assurance, and standard reference materials.

The Laboratory generates, evaluates, and compiles atomic, molecular, optical, and ionizing radiation data in response to national needs, develops and operates major radiation sources as user facilities, and maintains appropriate collaborations with other Laboratories in NIST, the Nation, and throughout the world. It conducts a major cooperative research program with the University of Colorado through the Joint Institute for Laboratory Astrophysics. The Laboratory's programs support the research community and industry in such areas as communication, defense, energy, environment, space, health, electro-optics, electronics, radiation, and transportation.

The Physics Laboratory consists of eight Divisions.

■ **Electron and Optical Physics Division.** Provides the central national basis for the measurement of far ultraviolet and soft x-ray radiation; conducts theoretical and experimental research with electron, laser, ultraviolet, and soft x-ray radiation for measurement applications in fields such as atomic and molecular science, multiphoton processes, radiation chemistry, space and atmospheric science, microelectronics, electron spectroscopy, electron microscopy, surface magnetism, and solid state and materials science; determines the fundamental mechanisms by which electrons and photons transfer energy to gaseous and condensed matter; develops advanced electron- and photon-based techniques for the measurement of atomic and molecular properties of matter, for the determination of atomic and magnetic microstructure, and for the measurement and utilization of ultraviolet, soft x-ray, and electron radiation; develops and disseminates ultraviolet, soft x-ray and electron standards, measurement services, and data for industry, universities, and government; and develops and operates well-characterized sources of electrons and photons including the NIST synchrotron ultraviolet radiation facility (SURF II), two scanning tunneling microscopes, and two scanning electron microscopes with unique magnetic imaging capabilities.

■ **Atomic Physics Division.** Carries out basic theoretical and experimental research into the spectroscopic and radiative properties of atoms and highly ionized species to provide measurement and data support for national needs in such areas as fusion plasma diagnostics, processing of materials by plasmas, spectrochemistry, and laser development; develops well-defined atomic radiation sources as radiometric or wavelength standards to meet national measurement needs; studies the physics of laser cooling and electromagnetic trapping of neutral atoms and ions; develops new measurement techniques and methods for spectral analysis and for the measurement of plasma properties; and collects, compiles, critically evaluates, and supplements spectroscopic data bases to meet major national demands for such data.

■ **Molecular Physics Division.** Determines spectroscopic properties of molecules, radicals, and their ions from experimental measurements of their spectra; applies advanced theoretical concepts to the analysis of spectra and to the use of spectroscopic data for the determination of molecular properties such as dissociation energies, potential functions, dipole moments, line shapes, and structures; develops advanced experimental techniques and instrumentation for obtaining, measuring, and interpreting molecular spectra; establishes secondary frequency standards; collects, compiles, and critically evaluates spectroscopic data and associated physical properties, and supplies data necessary for the calculation of thermodynamic functions; applies molecular spectroscopic techniques to the solution of measurement problems in areas such as the environment, energy and laser technologies, chemical kinetics, and materials science research; and develops theoretical descriptions of collisional, radiative, and nonradiative processes for applications to spectroscopic phenomena, atomic collisions, and state-selected kinetics.

■ **Radiometric Physics Division.** Provides national measurement standards and support services for ultraviolet, visible and infrared radiation to meet major national needs in such areas as health and safety, the lighting, photographic, and xerographic industries, solar measurements, and national defense; provides standards dissemination and measurement quality assurance services leading to accurate and uniform measurements of optical radiation throughout the Nation; conducts research in optical radiation, pyrometry, photometry, and quantum radiometry to provide competence necessary to improve the accuracy and extend the range of optical radiation measurements and develop standards and methods for both source and detector based radiometry; and develops standards and calibration procedures for spectroradiometers, spectrophotometers, electrooptical radiometric devices, and reflectance and transmittance measurements.

■ **Quantum Metrology Division.** Engages in a program of research characterized by strong coupling between advances in measurement technology and basic physics; addresses problems in the determination of fundamental physical constants and interacts with others in the Physics Laboratory and other Laboratories in NIST where work in fundamental quantities occurs; contributes to the extension and refinement of the electromagnetic scale and devises tests of basic symmetries and invariances; and maintains continuing efforts in several discipline areas including fundamental neutron physics, x-ray spectroscopy of atoms, molecules and simple solids, spectra of laboratory and astrophysical plasmas, and application of high accuracy measurements to the study of calculable spectra of basic scientific interest.

■ **Ionizing Radiation Division.** Provides primary national standards, dosimetry methods, measurement services, and basic data for application of ionizing radiation (x rays, gamma rays, electrons, neutrons, and radioactivity, etc.) to radiation protection of workers and the general public, radiation therapy and diagnosis, nuclear medicine, radiography, industrial radiation processing, nuclear power, national defense, space science, and environmental protection; conducts theoretical and experimental research on the fundamental physical interactions of ionizing radiation with matter; develops an understanding of basic mechanisms involved in radiation-induced chemical transformations and the parameters that influence the yields of short-lived intermediates, final chemical products, and biological effects; develops improved methods for radiation measurement, dosimetry, and radiography; develops improved primary radiation standards, and produces highly accurate standard reference data for ionizing radiation or radioactive materials; provides standard reference materials, calibrations, and measurement quality assurance services, to users such as hospitals, industry, states, and other federal agencies; and develops and operates well-eharacterized sources and beams of electrons, photons, and neutrons for primary radiation standards, calibrations, research on radiation interactions, and measurement methods development.

■ **Time and Frequency Division.** (Boulder) Maintains, develops, and improves the national standards for time and frequency and the time scales based on these standards; carries out research in areas of importance to further the fundamental improvement of frequency standards and their applications, focusing on microwave and laser devices, atomic and molecular resonances, and the measurement of fundamental physical phenomena and constants; adapts time and frequency standard devices and concepts to special scientific and technological demands; develops time and frequency measurement methods in the radiofrequency, microwave, infrared, and visible radiation regions; coordinates the national time and frequency standards, time scales, and measurement methods nationally and internationally in conjunction with the United States Naval Observatory; operates time and frequency dissemination services, such as radio stations and broadcasts, for the purpose of traceability to the national standards of time and frequency; coordinates these services nationally and internationally; evaluates existing services in terms of present and future user needs and implements improvements as appropriate; assists present and potential users to apply NIST time and frequency services effectively to the solution of their particular problems; provides publications and consultations, and conducts seminars and demonstrations relating to NIST time and frequency dissemination facilities and services; and performs research and development on new dissemination techniques and, as appropriate, implements improved services based on these studies.

■ **Quantum Physics Division.** (Boulder) Engages in long-term, high-risk research in quantum physics and related areas such as atomic and molecular collisions, spectroscopy and radiative interactions, chemical physics, optical and laser physics, gravitational physics, geophysical measurements, radiative transfer, and solar physics; performs basic, highly accurate measurements and theoretical analyses in these areas essential to the foundations of the Nation's science and technology; develops the laser as a refined measurement tool; applies state-of-the-art methods to measurements and tests of the fundamental postulates and natural constants of physics; engages in research in atomic, molecular, and chemical physics leading to the determination of key techniques and data essential to understanding, predicting, and controlling the properties of excited and ionized gases and the pathways of chemical processes; improves the theory and instrumentation required for measurements of astrophysical and geophysical quantities such as the cosmic distance scale, earth's gravity, and terrestrial distances; maintains, through its association with the Joint Institute for Laboratory Astrophysics (JILA) at the University of Colorado and JILA's Visiting Fellows Program, active contact with and expertise in advanced research in physics; and makes its scientific knowledge available to many other areas of NIST and to industry through publications, visits, and exchange of personnel.

ORGANIZATION OF REPORT

This technical activities report is organized in nine sections, one for the Physics Laboratory Office which includes the Fundamental Constants Data Center, and one each for the eight Divisions. For each Division the report consists of brief statements of the Division's mission and organization, followed by a discussion of current directions, highlights of the year's accomplishments, and a discussion of future opportunities.

Following the technical activities section are a series of Appendices which list: publications; invited talks; committee participation and leadership; workshops, conferences, and symposia organized; journal editorships; industrial interactions; other agency research and consulting; calibration services and standard reference materials; and a list of acronyms used in this report. Each appendix is grouped by Division; if a Division is not listed in a particular appendix it means that they had nothing to report in this category.

To obtain more information about particular work, the reader should address the individual scientists or their Division office, c/o Physics Laboratory, B160 Physics Building, National Institute of Standards and Technology, Gaithersburg, Maryland 20899. ▫

FUNDAMENTAL CONSTANTS DATA CENTER

B. N. Taylor

MISSION

- to provide an international information center on the fundamental constants (FC) and closely related precision measurements (PM);
- to analyze the consistency of measured values of the constants in order to test fundamental physical theory and to obtain sets of recommended values of the constants for international use;
- to administer the NIST Precision Measurement Grant (PMG) Program;
- to provide the editorship of the *Journal of Research of the National Institute of Standards and Technology*;
- to serve as the NIST-authorized organization for the interpretation of the International System of Units (SI) in the United States.

CURRENT DIRECTIONS

Measurement Uncertainty. Take advantage of the expertise of the Fundamental Constants Data Center (FCDC) in analyzing measurement data to contribute to an international effort under the auspices of the International Organization for Standardization (ISO) to generate a guide on expressing measurement uncertainty that will be followed worldwide.

Information Center. Maintain the FCDC's extensive collection of reprints and other material relating to the FC-PM field in order to respond to inquiries and carry out the next Committee on Data for Science and Technology (CODATA) least-squares adjustment of the constants, which is to be completed sometime in 1995 and will provide a new set of recommended values of the constants for international use.

1995 Constants Adjustment. Make initial preparations, such as surveying relevant work underway in laboratories throughout the world, for the 1995 constants adjustment.

Precision Measurement Grants. Implement policies that will ensure that the PMG program continues to attract proposals of the highest quality and provides maximum benefit to NIST.

NIST Journal of Research. Implement policies that will ensure that the NIST Journal of Research continues to be a widely read, highly respected, scientific publication and an attractive vehicle for NIST scientists to use to report the results of their research in measurement.

SI Units. Generate publications related to the SI and disseminate them widely in order to meet the information needs of the increased number of users of the SI arising from the Federal government's conversion to the SI.

HIGHLIGHTS

Guide on the Expression of Uncertainty. The FCDC assumed principal responsibility, in collaboration with C. E. Kuyatt, also of the Physics Laboratory, for drafting a Guide titled "Expression of Uncertainty in Measurement." This Guide is being prepared under the auspices of ISO, Technical Advisory Group 4 (TAG 4) in particular, at the request of the International Committee for Weights and Measures (CIPM). It is expected to be published by ISO in the name of seven international organizations, including the International Bureau of Weights and Measures (BIPM), the International Electrotechnical Commission (IEC), ISO, the International Union of Pure and Applied Physics (IUPAP), and the International Organization for Legal Metrology (OIML). It is to be used worldwide at various levels of accuracy and in a wide range of fields.

The third draft of the Guide, which is a 100-page document, was discussed at a January 1992 meeting of ISO/TAG 4, Working Group 3 (WG 3), under whose auspices it is being prepared. A fourth draft was subsequently written and circulated to all ISO/TAG 4/WG 3 members. Some 2000 copies of the resulting fifth draft were then distributed worldwide for comment. It was also sent to the members of ISO/TAG 4, which approved it, subject to editing based on the comments received. The final draft is now nearing completion, and it is expected that the ISO Technical Board will approve the publication of the Guide in early 1993 and that it will be published during the first half of 1993.

■ **NIST Policy on Statements of Uncertainty.** The development of the ISO Guide and the worldwide movement towards the adoption of the approach to expressing uncertainty in measurement on which the Guide is based, namely, that recommended by the CIPM, led NIST Director Lyons to appoint a NIST Ad Hoc Committee on Uncertainty Statements. C. E. Kuyatt and B. N. Taylor represented the Physics Laboratory on the Committee, which was charged with proposing a NIST policy on this critical subject. After due consideration, the Committee recommended, and the Director accepted its recommendation, that the NIST policy adopt in substance the CIPM approach. The written 3-page policy was distributed to all of the NIST staff and will become part of the NIST Administrative Manual. A short NIST Technical Note presenting, in the context of the new NIST policy, those aspects of the ISO Guide that will be of most use to the NIST staff in implementing that policy has been prepared by Taylor and Kuyatt and should be available in early 1993. The adoption at NIST of a uniform approach to expressing uncertainty in measurement should make it easier for the users of NIST measurement results to interpret them. Further, because the approach adopted at NIST is essentially that recommended by the CIPM, NIST statements of uncertainty will be consistent with current international practice.

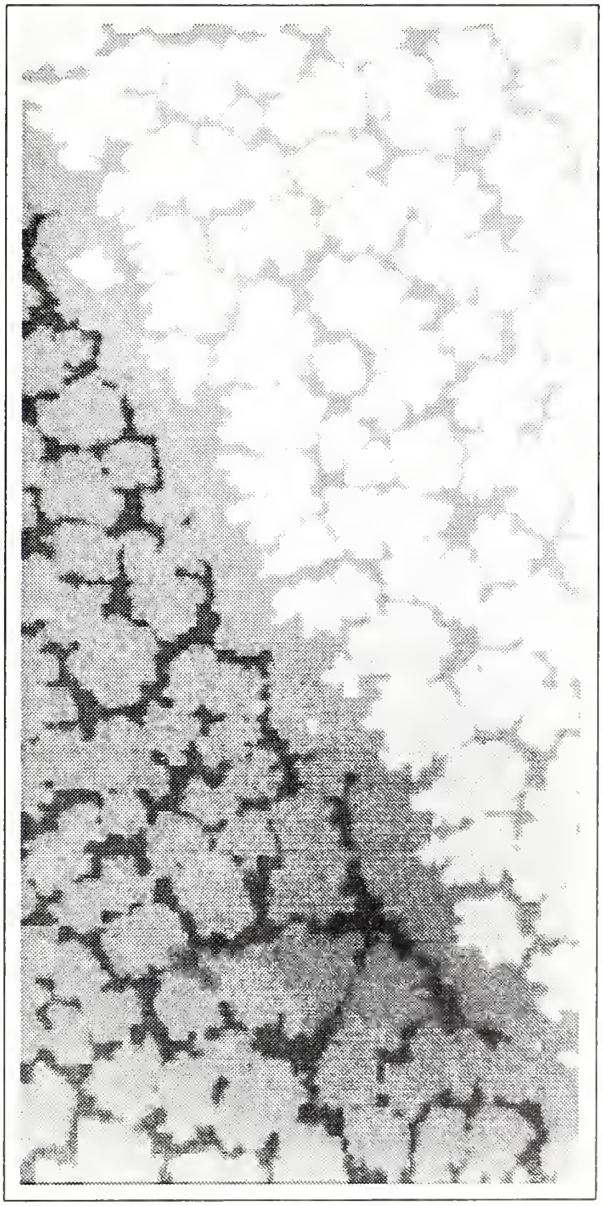
■ **Precision Measurement Grants.** The FCDC awarded, on behalf of NIST, new Precision Measurement Grants to Alex de Lozanne and Qian Niu of the University of Texas at Austin, and Thad G. Walker, University of Wisconsin-Madison. The grants are in the amount of $30,000 per year, renewable for two additional years. The aim of de Lozanne and Niu's project, "Quantum Charge Pump for a Current Standard," is to conduct experimental and theoretical studies on the realization of a quantum charge pump (QCP). Novel lithographic techniques made possible by the scanning tunneling microscope will be used to pattern the two-dimensional electron gas at a GaAs-A1GaAs interface. For a 750 MHz applied bias voltage and at a temperature of 2 K, the 50 nm features of the QCP should result in a dc current of 120 pA having a precision of 1 part in 10^8.

Walker's project, "Beta-Asymmetry Experiments Using Trapped Atoms," involves optically cooling and confining via radiation pressure short-lived radioactive atoms produced by an accelerator and spin polarizing the atoms by optical pumping. This will enable a variety of beta-decay experiments to be carried out with unprecedented precision. Walker's initial experiment will be to determine the beta-asymmetry parameter for the mirror nuclear decay of potassium 37 to argon 37. This measurement will provide a precision test of the so-called standard model of particle physics.

FUTURE OPPORTUNITIES

A principal focus of the FCDC's work in 1993 will be to complete and widely distribute the ISO Guide, "Expression of Uncertainty in Measurement." Another will be to prepare for the CODATA least-squares adjustment of the constants by reviewing the current status of various experiments underway in laboratories in different countries and providing the chairmanship of the CODATA Task Group on Fundamental Constants. The efforts of the FCDC will increasingly be devoted to this adjustment in 1993 and beyond until its completion and wide dissemination sometime in 1996. □

ELECTRON AND OPTICAL PHYSICS DIVISION



Overleaf

Growth of Chromium on a Single Crystal of Iron. The image is a scanning tunneling micrograph of a single crystal of iron on which an average coverage of 3.8 layers of chromium has been deposited. The area represented is approximately 500 nm by 1000 nm. The three shades of gray represent three different chromium layers, each differing by a height of 0.14 nm, with the lightest shade on top. The growth of chromium islands has been stopped with only 20% of a full layer left to be filled in. The diagonal structure, moving from top left to bottom right, results from a single-atom-high step in the iron substrate. These detailed images of chromium growth are helping to unravel the underlying principles of exchange coupling between magnetic layers. Exchange coupled magnetic multilayers are expected to play a key role in future magnetic devices based on the giant magnetoresistance phenomena.

ELECTRON AND OPTICAL PHYSICS DIVISION

MISSION

The Electron and Optical Physics Division is broadly chartered to advance the capabilities for absolute measurement of electron and photon interactions with matter, and to diffuse such capabilities into industry, academia, and other branches of Government. In pursuit of this mission, it maintains an array of research, measurement, and calibration activities. In particular, the Division

- provides the central national basis for absolute radiometry in the far ultraviolet and soft x-ray regions of the electromagnetic spectrum, which together span the photon energy range of 5 eV to 250 eV. This basis is maintained through a combination of ionization chambers, calibrated transfer standard detectors, and an electron storage ring, the SURF-II Synchrotron Ultraviolet Radiation Facility, which provides a dedicated source of radiation over this spectral range. SURF-II also supports a range of research activities by members of the Division, of other NIST organizational units, and external research groups.
- maintains specialized electron microscopy facilities for Scanning Electron Microscopy with Polarization Analysis (SEMPA), and Scanning Tunneling Microscopy (STM). The SEMPA facility provides unique capabilities for the study of surface magnetism, and has resulted in a wide range of collaborative research involving the magnetic recording industry. The STM facility is used for studies of surface electronic structure, particularly that associated with adsorbed atoms.
- performs theoretical and experimental research in atomic, molecular, surface, and condensed matter physics in support of its basic mission objectives.

ORGANIZATION

The Division consists of three groups, which together employ about 35 full-time equivalent members of staff, and during the past year had the equivalent of 11 Guest Researchers working full-time during visits of three or more months.

The Photon Physics Group (841.01) is primarily engaged in research in soft x-ray optics, x-ray emission spectroscopy and multiphoton processes. It also operates a reflectometry beamline at SURF-II that provides custom calibrations for the soft x-ray optics community, which is the only such dedicated facility in the United States.

The Far Ultraviolet Physics Group (841.02) is responsible for SURF-II operations and for radiometric calibration services in the far ultraviolet and soft x-ray spectral regions (spanning the wavelength range 5 - 200 nm). The latter mission is pursued by operation of two dedicated calibration beamlines at SURF-II: one primarily for custom calibrations of instrumentation, the other for calibration of photodiodes which are disseminated as transfer standards.

The Electron Physics Group (841.03) performs work on the frontiers of electron microscopy. It has particular expertise in polarized electron technology, which led to the development of the SEMPA technique. It also has designed and constructed some of the world's most sensitive scanning tunneling microscopes, which can resolve vertical displacements of about a picometer. These instruments are presently used for the study of a variety of surface phenomena, such as the microstructure of magnetic domains, thin-film growth, and the structure of complexes of adsorbed atoms. The Group has had a strong historical presence in the fields of electron-atom scattering and optical pumping of atomic beams, and has begun to apply its capabilities in these areas to the problem of laser control of atomic adsorption on surfaces.

CURRENT DIRECTIONS

The Division's activities fall into three categories: facilities operations, calibration and measurement services, and basic research.

■ **Operation of the SURF-II Synchrotron Ultraviolet Radiation Facility.** Operation of the SURF-II facility supports the Division's measurement services and research efforts, those of other NIST organizational units, and a variety of external users. The past year has seen the beginning of a major renovation of the facility, summarized below, which will eventually result in a substantial increase of user space and a general enhancement of amenities. However, the renovation has been accompanied by significant periods of downtime and some temporary problems with the performance of the storage ring. It is anticipated that construction work will be completed in the Spring of 1993.

■ **Calibration and Measurement Services.** The Division's activities in calibration and measurement services are centered around SURF-II. They have shown dramatic growth during the past year, largely due to increased world-wide interest in normal-incidence soft x-ray optics. For the past several years we have maintained a dedicated reflectometer system on beamline 7 (BL-7) at SURF-II, which is used primarily to determine reflectivities of multilayer optics, and for related investigations such as film dosimetry. In 1992 measurements were made on 180 samples, provided primarily by industrial laboratories and universities. These services are presently undertaken primarily as research collaborations, not on a reimbursable basis. As described below, a new beamline has been commissioned to support this activity, and we have begun procurement of a new reflectometer to accommodate the large, heavy optics that will be forthcoming in the field of projection lithography. Two other measurement services programs, of longer historical standing, have been relatively steady during the year. Spectrometer calibrations, done on BL-2, are carried out primarily in support of NASA programs in solar physics and XUV astronomy. NASA makes substantial financial contributions to the operation of this beamline, which was used by seven different groups during 1992 (such usage typically involves several individuals working full-time on BL-2 for a week or more). We also provide absolutely calibrated photodiodes as transfer standards. This work uses a dedicated beamline (BL-9) and a new dual grating monochromator that is mounted on BL-2 during calibration runs. A research effort is maintained to investigate improved photodiodes. As discussed below, this has had some success in developing solid-state photodiodes as an alternative to our existing photoemissive devices.

■ **Basic Research and Measurement Methodology.** The success of our research enterprise derives from its focus on the development and exploitation of novel measurement technology, and close interaction with our measurement services programs. The first aspect is best exemplified by the work of the Electron Physics Group, which has applied its expertise in polarized electron techniques, originally acquired for application to basic studies of electron-atom scattering, to the development of novel forms of microscopy in which it continues to maintain a role of world leadership. Its focus on the continuous advancement of measurement capabilities is founded on its internal capabilities for the design and construction of original instrumentation, on subsequent application to fundamental research questions in areas of prospective technological importance, and, when appropriate, collaboration in commercialization or other dissemination of these capabilities. The effectiveness of the Group in its interaction with industry was recognized by the award in 1992 of NIST's first William P. Slichter Award to Drs. Robert Celotta and Daniel Pierce. The principal research activities of the Photon Physics Group, the other main research-oriented group in the Division, are in soft x-ray physics, and are carried out in close association with the reflectometry service at SURF-II. Although the main profile this Group presents to the soft x-ray community is that of a provider of measurement services, its stature and credibility depend critically on the development of frontier measurement capabilities. The Photon Physics Group has also played a significant role in the development of single-atom detection technology through its involvement in resonance ionization mass spectrometry. Its research efforts in laser-atom interaction are largely driven by the needs of that field.

HIGHLIGHTS

Highlights of technical activities performed within the past year include:

■ **New Beamline Commissioned at the National Soft X-Ray Reflectometry Facility.** A new high-throughput, high-resolution beamline has been installed on the National Soft X-Ray Reflectometry Facility at the SURF-II storage ring, to expand the provision of calibration services to the x-ray lithography community. The new facility was designed to offer several significant improvements over the existing reflectometry facility on BL-7. The layout of the monochromator is shown in Fig. 1. First tests of monochromator throughput reveal a dramatic increase in

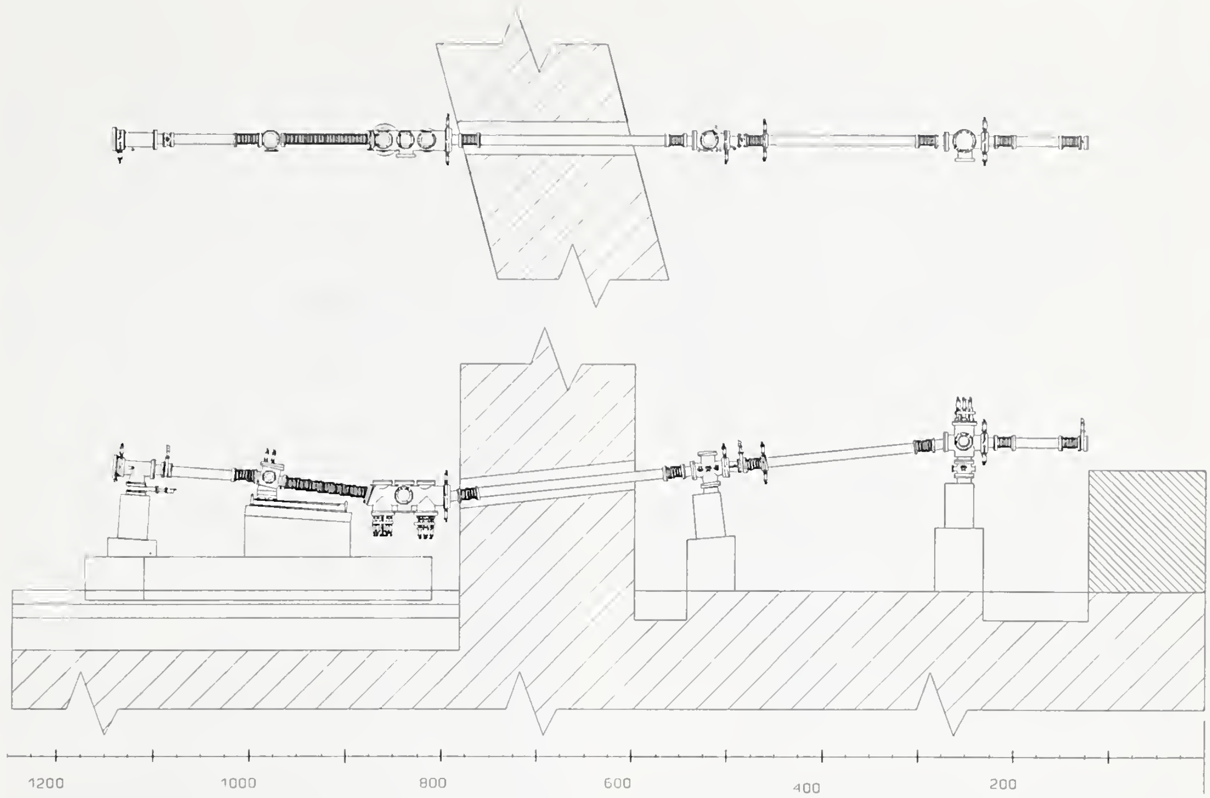


Figure 1 – Plan and elevation views of the recently-commissioned monochromator section at the National Soft X-Ray Reflectometry Facility. Dimensions are indicated in cm. The SURF-II storage ring is located above the cross-hatched region on the right. Shaded area in the center of the figure represents the shielding wall between the main beam hall and the present control room. The reflectometer chamber is to be attached on the left side.

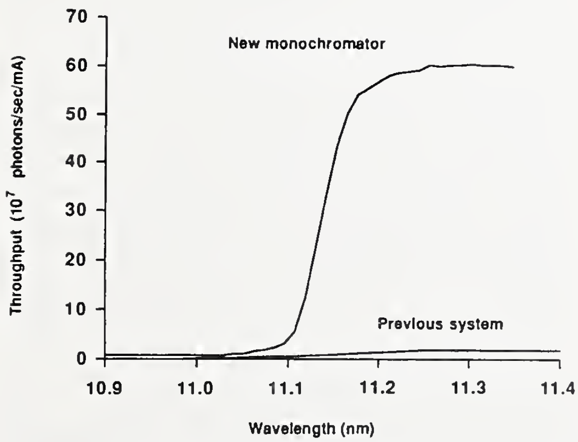


Figure 2 – Measured throughput near the beryllium K edge of the new monochromator system depicted in Fig. 1, compared to the previous system.

performance over that of the previous system, as shown in Fig. 2. In addition, we anticipate an increase in spectral resolution by a factor of 30, leading to increased sensitivity to weak and sharp features in reflectivity spectra. The focal spot size will be adjustable down to 0.1 mm, allowing much finer spatially resolved studies of component performance. Most importantly, the new reflectometer will be able to accommodate samples up to 35 cm in diameter, which will allow detailed measurement of the actual optical elements that will be used in projection x-ray lithography systems. First measurements of the throughput and resolution of the monochromator have now been made. Preliminary measurements of thin film absorption edges indicate that the monochromator has an order of magnitude greater throughput and a factor of three better resolution than our current facility. Several improvements are in progress, including refiguring of the focusing mirrors, to bring the performance of the beamline up to calculated specifications. (T. B. Lucatorto, C. S. Tarrio, and R. N. Watts)

■ **Alkaline Earth Contributions to the Valence Electronic Structure of High-Temperature Superconductors.** It has been generally assumed that the alkaline earth elements in high-T_c

compounds do not contribute to the valence electronic structure in these materials or to the valence band in other insulating compounds. However, new evidence from soft x-ray emission spectroscopy shows that alkaline earth species make small but measurable contributions to the valence electronic density of states. We have recently examined the radiative decay of photon-excited Ba 4d vacancies in BaF_2, $BaTiO_3$, $YBa_2Cu_3O_{7-\delta}$, and $PrBa_2Cu_3O_{7-\delta}$. The measurements clearly show a distinctive Ba contribution to the valence density of states. The result is indicative of some covalent character in the bonding of Ba even in highly ionic compounds.

The $YBa_2Cu_3O_{7-\delta}$, compound is a (famous) superconductor, whereas $PrBa_2Cu_3O_{7-\delta}$ is an insulator. It has been proposed that the difference between them is due to mixing of Pr and Ba among the sites occupied by Y and Ba, with an accompanying change in electronic structure. However, our measurements indicate that the barium partial density of states for the two compounds is identical. (D.R. Mueller)

■ **Measurement of AC Stark shifts in Ca and Xe Rydberg levels.** The AC Stark shift describes the perturbation of atomic energy levels by an oscillatory electromagnetic field. This effect is especially important in understanding the interactions of atoms with intense laser radiation. Theory predicts that highly monochromatic laser radiation of relatively low frequency should induce a net upwards shift in the energy of a Rydberg level by an amount very close to the *ponderomotive energy*, which is simply the average kinetic energy imparted to a free electron by a harmonic radiation field. However, many previous experiments probing the AC Stark shifts of Rydberg levels show dramatic departure from the expected near-ponderomotive behavior. To determine if these discrepancies reflect incomplete understanding of the AC Stark effect or if experimental difficulties obscured the results, we made direct measurements of AC Stark shifts in three Rydberg levels of calcium and 14 Rydberg levels in xenon perturbed by intense laser radiation (up to 10^{10} W/cm^2). We found excellent agreement between the observed energy shifts and the predictions of simple ponderomotive theory. In addition, detailed modeling of the expected results, including thorough treatment of the laser-atom interactions, gave excellent agreement with the observed energy shifts and lineshapes. These results should restore confidence in the validity of the simple ponderomotive interpretation of Rydberg level AC Stark shifts. (J.-B. Kim, T. B. Lucatorto, T. J. McIlrath, T. R. O'Brian)

■ **Generation of VUV Laser Radiation for Measurement of Lamb Shift in Helium.** The ultimate goal of this experiment is a precise measurement of the $1s^2\ ^1S_0 - 1s2s\ ^1S_0$ transition energy in He, by using Doppler-free two-photon spectroscopy with highly monochromatic VUV radiation (120.3 nm). This transition energy can be combined with the extensive measurements of He excited state energies made by C. Sansonetti and J. Gillaspy of the Atomic Physics Division to determine the ground state Lamb shift for the He atom. In addition to providing a test of theoretical calculations of quantum-electrodynamic effects in two-electron atoms, this determination could provide an improved frequency standard for the VUV spectral region. The main difficulty faced by this experiment is the generation of VUV radiation of sufficient intensity to drive the two-photon transition. During the past year, we identified a promising new mechanism for attaining the requisite intensity. Using far off-resonance four-wave mixing in krypton, we generated radiation at a wavelength of 120.3 nm, employing only the harmonics of a single laser frequency. Previous schemes required at least two different fundamental frequencies and harmonics, significantly increasing the demands for precise wavelength metrology and laser frequency stabilization. The new VUV generation method is surprisingly efficient, given the large detuning from the krypton resonance (about 1000 cm^{-1}). We have already generated VUV laser powers about three times larger than we predict will be necessary to measure the He Lamb shift, and relatively simple changes in the laser system should result in significantly greater VUV power. In addition, significant progress was made in the design and construction of the complex optical system required for the VUV Doppler-free measurements. (K. Baldwin, T. B. Lucatorto, T. J. McIlrath, T. R. O'Brian)

■ **Reference data for Resonance Ionization Mass Spectrometry.** One of the main limitations on the analytical sensitivity of mass spectrometry is the presence of isobaric interferences, which are almost always present when non-specific means of sample ionization are employed. A high degree of specificity can be imposed in the ionization process by using a laser tuned to a resonance transition of a given analyte, which can result in efficient multiphoton ionization of that analyte without significant ionization of isobaric species. Use of this technique, known as resonance ionization mass spectrometry (RIMS), is growing rapidly. Its applicability to any given element requires that a suitable multiphoton ionization pathway be identified, which is not a straightforward matter for most end-users of the technique. Working closely with the analytical community, and with support from the Office of Health and Environmental Research of the Department of Energy, we provide critical analyses of alternative schemes for targeted elements. This work involves the identification of resonant single- or multi-photon transitions between an atomic ground state and excited states that can be driven at available laser frequencies, and estimation of the photoionization cross sections of the excited states. Much of this information cannot be obtained from existing experimental data, so we derive it from atomic structure calculations in the Hartree-Fock or configuration-interaction approximations. Our results are disseminated in the form of data sheets published in the journal *Spectrochimica Acta*. In 1992, data sheets for Sb, Bi, P, Na, and Sn were published, and work on eight additional elements was completed. During the past three years, 33 elements have been covered. (E. B. Saloman)

■ **Major Facility Renovation at SURF-II.** During the past year a plan for major expansion and facility upgrade of SURF-II was completed. It will eventually result in an increase of user space by about 50%. On September 15, 1992, actual construction work began, involving extensive renovations of the control room area and the electrical system throughout the facility. By mid-December, the original electrical system had been replaced by new feedlines and circuit breaker panels, which nearly triple the electrical power available. All of the power for beamlines in the main experimental areas is now provided by local circuit panels, and there is reserve capacity for many additional circuits. The next phase of the project, to begin in mid-January 1993, involves the demolition of the wall between the control room and the adjacent power room to make room for the newly installed XUV optics characterization beamline. In addition, a false wall in the corner of the control room will be removed to provide additional user space, and a doorway is to be opened from the control room into three recently acquired adjacent rooms. It is planned to move the control panel into one of those rooms, to allow for beamline expansion in its current location. Completion of all work is scheduled for March, 1993. (A. Hamilton and R. P. Madden)

■ **SURF-II Calibrations for Space Missions.** During 1992 there were 12 instruments and gratings calibrated by 7 user groups at the Spectrometer Calibration Facility (BL-2) at SURF-II. Users of the facility included Johns Hopkins University, National Institute of Standards and Technology, Naval Research Laboratory, University of Colorado Laboratory for Atmospheric and Space Physics, University of Virginia, and NASA/Goddard Space Flight Center.

In April 1992, the first of a planned series of ten Atmospheric Laboratory for Applications and Science (ATLAS) missions was flown aboard a NASA shuttle mission. One of the instruments in the ensemble was the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) from NRL which was calibrated at BL-2 both before and after the flight. The ATLAS missions will provide a systematic collection of data over a complete 11 year solar cycle, to establish long-term benchmarks for the understanding of climatic change, atmospheric conditions, and solar variability. Such benchmarks are essential, for example, for evaluating the effects of human activities on the abundance of stratospheric ozone, which is strongly influenced by solar activity.

The Extreme Ultraviolet Explorer (EUVE) was launched in June 1992 on a Delta II rocket. Several of the optical components of the EUVE spectrometer, including the three variable line-spaced gratings, were previously calibrated at the Spectrometer Calibration Facility. The EUVE will perform an all-sky survey at wavelengths between 7 and 76 nm to create a comprehensive catalog of astronomical objects located within 100 parsec of the solar system. (M. Furst, R. Graves, and T. Hall)

■ **High-Resolution VUV Spectroscopy of N_2.** The photoabsorption cross section of molecular nitrogen at wavelengths in the vicinity of 83.3 nm is of great interest in ionospheric physics. This wavelength region includes three O^+ emission lines whose absolute intensities are being used as diagnostics of the electron density in the ionosphere. Inference of an absolute intensity from an observation requires an estimation of the absorption of these lines by atmospheric nitrogen. Previous experimental measurements of N_2 absorption in this region of the spectrum, which is fairly complex, have yielded absolute photoabsorption cross-sections that disagree by more than a factor of two, and were carried out

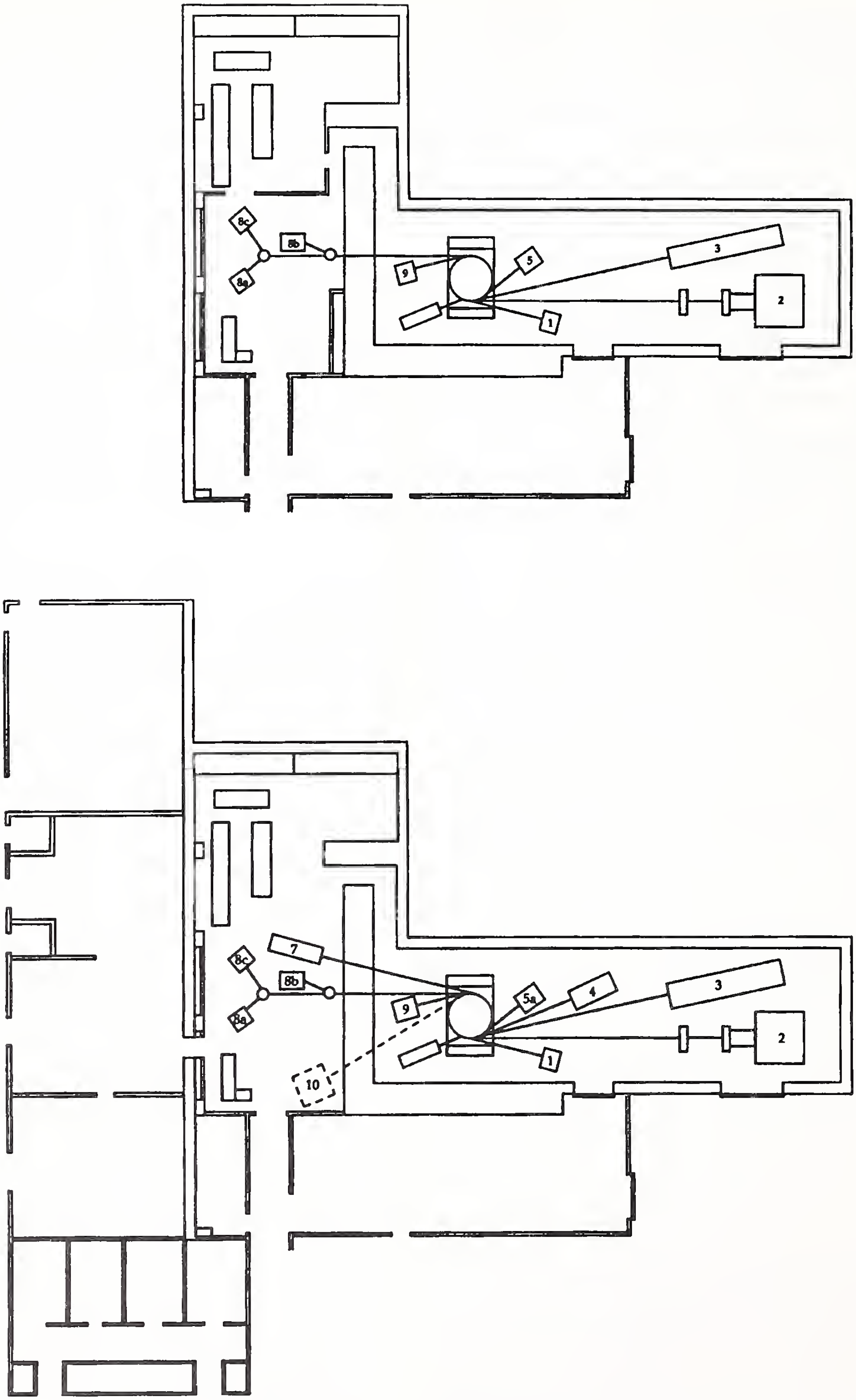


Figure 3 – SURF-II experimental and support space and beamline layout. *Above*, prior to the renovations of 1992; *below*, after. Beamlines: (1) TGM, 8-60 nm, surface science; (2) white light, spectrometer calibration; (3) 6.65 m off-plane Eagle spectrometer, 40-250 nm, high resolution spectroscopy; (4) 2-m NIM (new location), 40-200 nm, PES, fluorescence, gas phase experiments; (5) 2-m NIM (old location); (5a) 13 nm broadband, nanodetector/microscope; (7) GIM, 4-40 nm, x-ray optics; (8a) TGM, 8-60 nm, surface science; (8b) 3-m GIM, 4-80 nm, PE, optical properties; (8c) TGM, 40-200 nm, general purpose; (9) TGM, 4-55 nm, PE, detector calibrations; (10) future grazing incidence instruments, 2-20 nm.

at too low a resolution to reveal the effects of specific rotational transitions. The 6.65 m spectrometer on BL-3 at SURF-II was used to measure N_2 photoabsorption at a resolution of 10^5, the highest yet employed in any absolute cross-section measurement in this region. The results are believed to have an absolute accuracy of 20%, and are being incorporated in ionospheric models being developed by collaborators at the Naval Postgraduate School. (A. Asfaw, J. Fortna, M. L. Furst, L. R. Hughey, D. C. Humm, H. Morgan, and H. Seyoum)

■ **Calibration Services and Device Development for Far-Ultraviolet Radiometry.** A major advance in the far UV calibrations program occurred via the commissioning of a new dual-grating monochromator system. This system will greatly enhance the accuracy of windowed photodiode calibrations.

A variety of promising new detectors with potential applications in the far UV were studied during 1992. We have continued our long-term study of Schottky devices, consisting of GaP or GaAsP photodiodes with thin Au films on their outer surfaces. These studies have identified some improvements over silicon technology. We are also collaborating with industry to improve present silicon technology to produce silicon photodiodes of sufficient quality to replace our present photoemissive transfer standards. This collaboration has led to the first commercial production of photodiodes with integral metal filters, which serve as narrow-band detectors.

Twenty-five calibrations of transfer standard detectors were performed in 1992, for applications in aeronomy, plasma diagnostics, solar physics, and astronomy. In addition a number of calibrations of special-purpose detectors and filters were carried out as research collaborations. (L. R. Canfield and R. Vest)

■ **Demonstration of Optical Pumping of Chromium.** The Electron Physics Group's experience with optical pumping of atoms, gained in previous work on spin-polarized electron scattering from aligned and oriented atoms, is being deployed to control the motion of atoms as they adsorb onto a surface. The long-term goal of this effort is the development of a practical technique for laser-controlled lithographic fabrication of atomic-scale structures on surfaces. Such a technique requires an atomic species that can be effectively manipulated by a laser, and which is also of technological importance as an adsorbate. To date, the only experiments that have been carried out in this area have used alkali atoms, for which techniques of laser control have been developed to a high degree, but which are extremely reactive and hence unsuitable for the fabrication of practical devices. Chromium, on the other hand, is a durable adsorbate with a number of desirable properties, and we have now demonstrated that it can be effectively manipulated by a laser.

During the past year, we have assembled the necessary laser and atomic beam equipment to manipulate a chromium beam. Our initial experiments have shown that chromium atoms can be optically pumped and spin polarized. Experiments in progress will involve using a laser "molasses" to cool the atomic beam, which will then be sent through a standing-wave laser field. The standing-wave field will act as a series of cylindrical lenses, focusing the atomic beam into a periodic array of lines on a surface. (R. J. Celotta, J. J. McClelland and R. Scholten)

■ **Growth of Ultra-thin Magnetic Films.** The microscopic aspects of the growth and resulting surface microstructure of very thin (0-10 atomic layers thick) films of iron and chromium have been investigated with scanning tunneling microscopy (STM) and reflection-high-energy-electron diffraction (RHEED) measurements. Numerous details of the growth mechanisms of Fe films have been elucidated by this work, such as the surface diffusion of Fe atoms on Fe surfaces and the effect of this diffusion on the growth and roughness of the films. We have performed the first comparison ever made of RHEED measurements with *real space* views of the growth front, as obtained by STM. Since RHEED is one of the main *in situ* diagnostics of molecular-beam epitaxy, we believe that this type of comparison will find widespread application.

Investigation of the growth of Cr films on Fe whiskers has shown that room-temperature growth leads to kinetically limited roughness of the film, whereas layer-by-layer growth takes place at higher temperatures. Analysis of the Cr film roughness explains the appearance of only the long period oscillations in the exchange coupling observed in SEMPA measurements on Fe/Cr/Fe sandwich structures. (R. A. Dragoset, D. T. Pierce, and J. A. Stroscio)

■ **Inverse Isotope Effects and Models for High Tc Superconductivity.** Models of high-temperature superconductivity based on electronic mechanisms must explain both the large values of T_c and the small isotope effect that is observed in experiments. Our previous theoretical investigations have highlighted the difficulties of accounting for both these facts in the context of existing models: high-T_c compounds are known to have substantial electron-phonon interactions, which our calculations demonstrated would lead to isotope shifts considerably larger than those actually observed. Our work during the past year has demonstrated that an electronic mechanism with an *inverse* isotope effect can easily result in predicted isotope shifts that are consistent with experiment. (D. R. Penn and M. L. Cohen)

■ **Magnetic exchange coupling in Fe/Ag/Fe multilayers.** Last year's report discussed our finding that the exchange coupling in Fe/Cr/Fe multilayers oscillates between ferromagnetic and antiferromagnetic as a function of the Cr spacer thickness, and that the coupling periodicities are determined by the size and shape of the bulk Cr Fermi surface. At that time Fe/Cr/Fe was the only system that had been investigated in sufficient detail to test the predictions of theoretical models. We therefore began investigations of other systems, in particular the Fe/Ag/Fe multilayer. As in our previous Fe/Cr/Fe studies, Fe/Ag/Fe sandwiches were grown with wedge-shaped spacer layers. A schematic of our sample is depicted in Fig. 4. RHEED was used to measure the atomic order and thickness of the

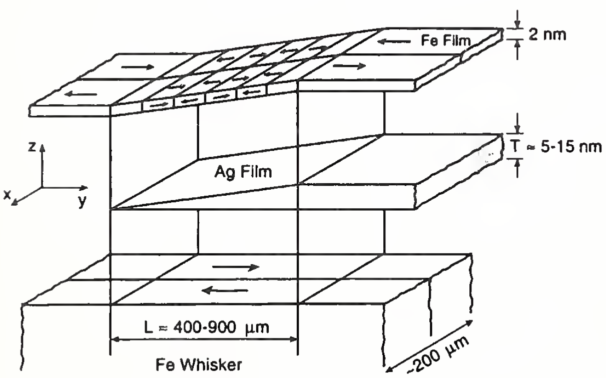


Figure 4 – Schematic of magnetic multilayer "wedge" used in experimental studies of exchange coupling. An iron whisker with a very uniform surface provides the substrate for a silver spacer layer of variable thickness. A uniform iron layer is deposited on top of the silver (view is exploded for visual clarity). The magnetic domains are indicated schematically, the arrows indicating the direction of magnetization within each domain. The magnetization vector is found to oscillate as a function of thickness of the silver layer, as shown in Fig. 5.

spacer; and SEMPA measured the magnetic coupling. Previous researchers had not been able to observe any oscillatory coupling in Fe/Ag/Fe, but we found that by growing atomically well-ordered multilayers, oscillatory coupling could be observed. The magnetic coupling was composed of two oscillatory components with periods of 2.37 and 5.73 Ag layers, and the oscillations persisted for Ag spacers up to at least 50 layers thick. These results are displayed in Fig. 5. The periods were consistent with a coupling length scale determined by spanning vectors of the Ag Fermi surface. (R. J. Celotta, M. H. Kelley, D. T. Pierce, and J. Unguris)

■ **Phenomenology of Oscillatory Magnetic Exchange Coupling.** Observations of oscillatory magnetic exchange coupling in magnetic thin film structures have stimulated numerous theoretical and experimental investigations. We have developed a simple model for the exchange coupling that includes the essential physics, have worked out its predictions for a variety of multilayer systems, and made comparisons with experimental data. We find that all experimentally measured periods for the oscillatory coupling are consistent with theories in which the periods are determined by properties of the Fermi surface of the spacer layer. (M. D. Stiles)

FUTURE DIRECTIONS

During the past several years a consensus has developed that the Division should look for opportunities to apply its expertise in atomic

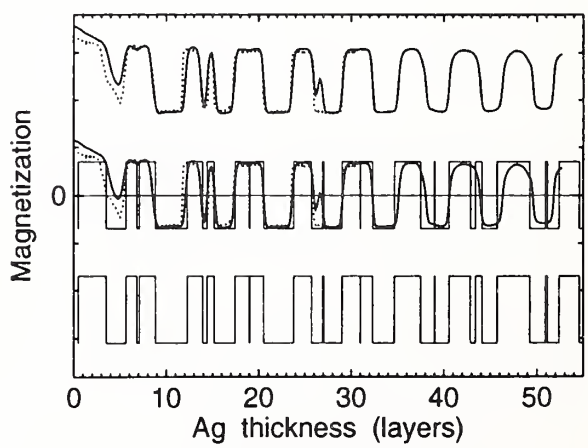


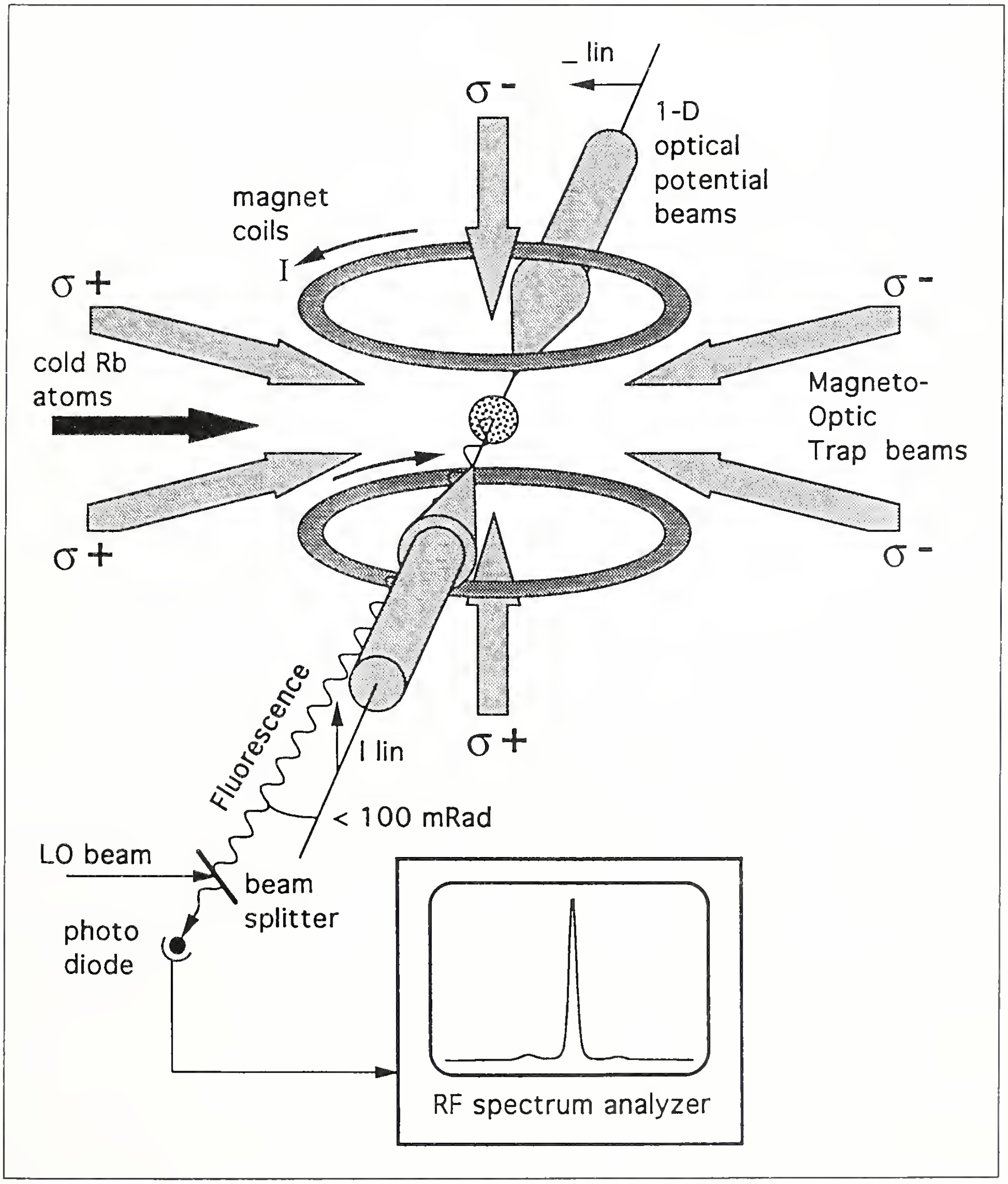
Figure 5 – Top frame: Magnetization (in *y* direction) of Fe overlayer of wedge depicted in Fig. 4, as a function of Ag spacer thickness; solid and dotted lines depict results from two different samples. Bottom frame: Results of a model calculation which assumes the oscillations to be dominated by two Fourier components, and the magnetization to take one of two values (positive or negative). The phases, amplitudes, and frequencies of the two Fourier components are determined by fitting to experimental data. Middle frame: Superposition of top and bottom frames.

and molecular physics to areas of emerging technological importance. This has resulted in a notable shift in the nature of our research activities, which is likely to continue.

■ **X-Ray Optical Characterization and X-Ray Emission Spectroscopy.** The Photon Physics Group has acquired a position of leadership in soft x-ray optical characterization and in x-ray emission spectroscopy, both of which are concerned primarily with condensed-matter and surface physics issues. The high visibility of and support for the soft x-ray program derive primarily from its importance to x-ray projection lithography. The long-term prospects for projection lithography are contingent on its being proven a competitive method for fabrication of semiconductor components in a production environment, and there are a number of critical technical issues that may be decided within a few years. Thus attention must begin to be given to other aspects of soft x-ray imaging, such as microscopy. Our program in x-ray emission spectroscopy will continue to change due to the departure of its senior investigator, D. Ederer. A very promising new direction for this work has been identified: the use of spectroscopy for *in situ* characterization of thin-film and multilayer fabrication processes. This fits well with the x-ray optics program, as it will provide capabilities for elucidating the growth mechanisms that govern the multilayer fabrication process, and it should also benefit from the surface characterization capabilities that have been developed by the Electron Physics Group.

■ **Laser Control of Atomic Deposition on Surfaces.** In the Electron Physics Group, a decision has been made to shift existing effort in electron-atom scattering towards the issue of laser control of atomic deposition on surfaces, which has been discussed briefly above. In many ways the Group provides a uniquely promising home for work in this area, since it has outstanding capabilities for analyzing "nanostructures" on surfaces by STM and for microscopic determination of magnetic properties. Development of integrated approaches to the fabrication and characterization of such structures would constitute an important advance of physical measurement techniques into the realm of nanotechnology. □

ATOMIC PHYSICS DIVISION



Overleaf

Quantized Motion of Trapped Atoms. The apparatus, shown schematically, captures and cools atoms from a laser-cooled Rb atomic beam, using a combination of laser beams and magnetic fields (magneto-optic trap). The atoms are cooled to a few microkelvins, and then trapped in a one-dimensional periodic potential created by a pair of counterpropagating, interfering laser beams. High resolution spectroscopy, performed by heterodyning the fluorescence emitted by the trapped atoms, shows that the atoms undergo quantized motion in the sub-wavelength-size potential wells. These studies are the first of their kind for optically trapped atoms, and may lead to lower temperatures, higher density, and quantum manipulation, such as squeezing, of the atoms, as well as to new nonlinear optical materials.

ATOMIC PHYSICS DIVISION

MISSION

The Atomic Physics Division carries out a broad range of experimental and theoretical research in atomic physics, including the atomic radiation of plasmas. The Division

- carries out basic theoretical and experimental research into the spectroscopic and radiative properties of atoms and highly ionized species;
- provides measurement and data support for specific needs in such areas as fusion plasma diagnostics, processing of materials by plasmas, spectrochemistry and laser development;
- develops well-defined atomic radiation sources as radiometric or wavelength standards;
- studies the physics of laser cooling and electromagnetic trapping and manipulation of neutral atoms and ions; and
- critically evaluates and compiles spectroscopic data bases on wavelengths, energy levels, transition probabilities, and line widths and shifts.

These activities support many areas of science and technology. For example, there is strong demand for the detailed understanding of atomic processes in industrially applied plasmas, both for modeling purposes and diagnostics. This has arisen from the widely applied plasma etching process for semiconductors as well as from surface cleaning by plasmas and materials deposition by plasma sputtering techniques. The understanding of these processes on the atomistic level is the key to optimizing operating conditions and to achieving competitive advantages. Furthermore, process monitoring and modeling in plasma chemistry, in spectrochemistry and medical applications are possible on a fundamental level only with reliable atomic radiation and collision data.

Urgent demands for spectroscopic data exist in VUV and X-ray laser physics. Transition energies and radiative decay rates of highly stripped ions are essential in the search for and the modeling of potential new laser systems. VUV and X-ray laser research continue to be important in defense work as well as for biological and biomedical studies.

Research on magnetic fusion energy has become very sophisticated and is increasingly directed towards optimizing fundamental physics questions. Thus, the atomic data we produce for highly stripped, heavy ions are essential for evaluating the effects of impurities on the plasma energy balance and for modeling ion transport. They are also needed for plasma diagnostics such as the measurement of ion temperatures. The area of highly stripped ions is also the natural laboratory in the fundamental quest for the ultimate atomic structure theory that properly considers all relativistic and QED effects.

Our vacuum ultraviolet radiometry work with plasma sources provides miniaturized calibrated radiation sources that are used as components of spectrometer systems on spacecraft, such as the Hubble Space Telescope. Also, we develop spectroradiometers for UV lithography applied in semiconductor fabrication.

ORGANIZATION

The Division is organized into four technical groups—atomic spectroscopy, atomic theory, plasma radiation, and laser cooling—and in each group several research projects are pursued. Some of these involve collaborations with other groups, either within the Division, with other divisions of the Physics Laboratory or with outside groups. The Division has currently 17 professional staff members, 3 Postdocs, and 9 long-term (>3 months) guest scientists.

CURRENT DIRECTIONS

Our principal current work areas are briefly as follows:

- **Atomic Data Production.** We are producing a large variety of atomic structure and collision data through innovative experimental and theoretical approaches, concentrating on highly ionized atoms as well as neutral helium. The new electron beam ion trap (EBIT) facility, soon to become operational, will greatly increase our capabilities.

■ **Physics of Laser Cooling.** We study the basic physics of laser cooling and electromagnetic trapping of neutral atoms, and the interaction of atoms and radiation in order to develop applications of these studies to new classes of physical measurements, such as high resolution spectroscopy, atomic clocks, Bose-Einstein condensation, and atom optics.

■ **Plasma Spectroscopy.** The Division is also engaged in plasma spectroscopy, i.e., the use of spectral radiation as a non-intrusive diagnostic of technical plasmas (RF cells) and research on the effects of plasma environments on atomic radiation, mainly spectral line broadening.

■ **Data Compilations.** Two data centers located in the Division critically evaluate and compile atomic energy levels, wavelengths, transition probabilities, and line shape parameters.

■ **VUV Source Radiometry.** Well-defined atomic radiation sources are developed, improved and maintained as VUV radiometric and wavelength standards, and special calibration services are provided.

HIGHLIGHTS

■ **Spectral Data for Astrophysical Applications.** The high quality of stellar spectra being obtained by the Goddard High Resolution Spectrograph (GHRS) on the Hubble Space Telescope has opened to astronomers the opportunity for studies of the abundances of heavy elements and isotopes in stars. But for many species interpretation of the GHRS spectra is limited by the low accuracy of existing wavelengths, oscillator strengths, and isotope shifts for the species of interest.

We have undertaken a program of laboratory observations to provide improved data needed for interpretation of these stellar spectra, which have, for example, played a critical role in determining the elemental and isotopic abundances of mercury in the chemically peculiar star chi Lupi. In support of the work by Leckrone and coworkers at NASA Goddard we have observed the Hg III spectrum on our 10.7-m normal incidence vacuum spectrograph. By using lamps containing separated isotopes we have measured the wavelengths and isotope shifts of selected lines of Hg III with an uncertainty of 0.002 Å. These data show that both singly- and doubly-ionized Hg in the atmosphere

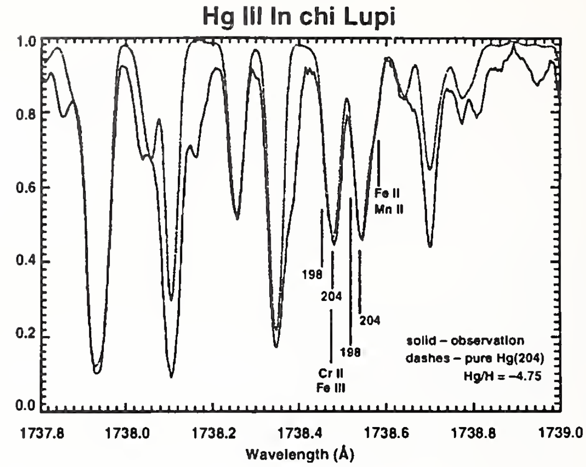


Figure 1 – GHRS spectrum of chi Lupi at 1738 Å. The solid line is the GHRS spectrum and the dotted line the synthetic spectrum generated using the precise Hg III wavelengths and isotope shifts measured in our laboratory. Our measurements were essential to the interpretation of Leckrone et al showing that the doubly-ionized Hg in chi Lupi is pure ^{204}Hg.

of chi Lupi consist of nearly pure ^{204}Hg, the heaviest naturally occurring Hg isotope (Fig. 1). This result disagrees with some predictions of the diffusion model of the stellar atmosphere. Without our precise new data for Hg III this important result could not have been obtained. (J. Reader, C. Sansonetti)

■ **Reference Wavelengths for Laser Spectroscopy.** We previously reported a determination of the He 2^1S binding energy based on measurements of the transitions $2^1S - n\ ^1P$ (n = 7-74) with an uncertainty less than 3 parts in 10^{10}. We have made additional investigations of systematic factors that may affect this result at a level comparable to our reported uncertainty, including a redetermination of the correction for phase dispersion on reflection from the aluminum coatings of our Fabry-Perot interferometer plates.

For this determination, we have measured the wavelengths of more than 100 lines of molecular iodine in the region 560-657 nm using 7 mm and 218 mm Fabry-Perot etalons. The spectrum was observed by Doppler-free frequency modulation spectroscopy, which resolves the hyperfine components of the lines. All of the iodine lines are measured with an uncertainty of less than 1.3 MHz. Since these lines are easily observed in a room temperature iodine cell, they will provide secondary wavelength standards for laser spectroscopy and for calibration of wavemeters and interferometers. (C. Sansonetti)

■ **Observation of Spectra of Importance for Tokamak Diagnostics.** In a continuing collaboration with the University of Texas, spectra of highly ionized atoms needed for tokamak plasma diagnostics were obtained by sample injection into the TEXT tokamak plasma. Spectral lines of the palladium and silver isoelectronic sequences were identified from Er to Pt. This range includes tungsten, which has been proposed for possible use in the next generation ITER tokamak. Further observations were also made with the single beam Glass Development Laser (GDL) at the University of Rochester. The observations for Fe will be used as the basis for a complete description of the spectra of highly ionized Fe between 10 and 200 Å. (J. Reader, J. Sugar)

■ **Major Atomic Data Conference Held at NIST.** The 4th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas was organized and hosted by the Atomic Physics Division at NIST on September 14-17. There were 170 registered attendees, with 26% foreign participation. This represented a doubling of the size of the last meeting in this series held 3 years ago in Amsterdam. The meetings bring together users and producers of atomic data and focus on the most critical data needs. Interdisciplinary data needs were represented by users from the space astrophysics, fusion energy research, x-ray laser, and spectrochemistry communities. Also, recent work in the establishment, maintenance, and access to atomic data bases was presented. NIST activities were featured very prominently in this area. (J. Sugar)

■ **New multiphoton ionization and inner-shell photoabsorption experiment.** An experiment developed at AT&T Bell Labs for multiphoton ionization of krypton followed by XUV photoabsorption produced well-resolved spectra not previously seen. By means of Hartree-Fock calculations carried out at NIST, these absorption spectra were identified as inner-shell excitations of Kr II, Kr III and Kr IV. This novel experiment may be applied to any gaseous species to provide inner-shell absorption spectra of multiply ionized atoms not accessible by any other method. (J. Sugar)

■ **Atomic Spectroscopic Database and New Data Compilations.** The Data Centers on Atomic Energy Levels and Atomic Transition probabilities have combined to build a computer-readable spectroscopic database intended eventually to cover all atoms and atomic ions for which data are available. The database includes wavelengths, energy levels, and transition probabilities. The system allows sorting and retrieval according to spectrum, wavelength region, etc., and covers all wavelengths from about 1 Å to the mm region. We have loaded into the database our evaluated data on energy levels for more than 600 spectra, as well as on transition probabilities for more than 200 spectra. With financial support from the space astronomy and fusion energy research communities, pertinent parts of the database will be exported (or linked) to special databanks established by these communities. Our most recent additions of evaluated data include energy levels for all zinc spectra, highly ionized manganese and singly ionized oxygen. Wavelength tables were completed for sulfur, O II and the higher manganese spectra, and transition probability work continued on the carbon, nitrogen and oxygen spectra as well as singly ionized argon. (W. Martin, J. Sugar, W. Wiese, D. Kelleher)

■ **Nuclear Size Correction to the Electron Self Energy.** The distribution of charge in the nucleus influences the quantum electrodynamic (QED) corrections to the structure of atoms, and the effect on the self energy correction has been difficult to quantify. We addressed this issue by calculating the nuclear size effect on the self energy in high-Z hydrogenlike atoms. Besides providing results for a broad range of special cases, we studied the nuclear model dependence, and the charge radius dependence of the effect. The hydrogenic value is not only important for tests of QED in high-Z hydrogenlike atoms; it also gives a first approximation to the correction in high-Z few-electron atoms and in inner shells of heavy neutral atoms. The strong dependence of this correction on the nuclear charge Z is illustrated in Fig. 2. This information is important for understanding atomic spectra for wavelength standards and plasma diagnostics, for example.

Previous calculations of this correction were confined to high nuclear charge numbers Z, and have numerical uncertainties that are of order 25% of the effect, or higher. Our calculation extends from $Z = 26$ to $Z = 100$, with an estimated numerical precision of about 0.003% of the size correction in the best case. As a consequence, the uncertainty in the predictions for this effect is no longer limited by calculational uncertainties, but is now dominated either by the nuclear model dependence, which is of order

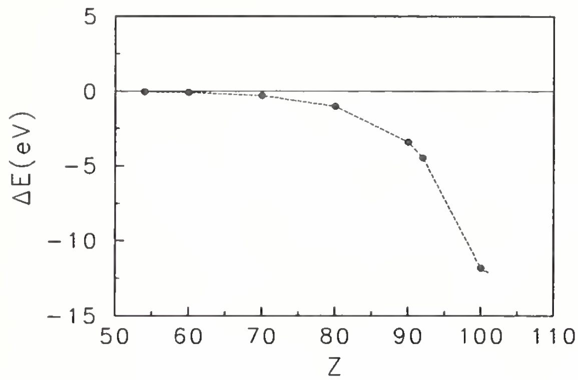


Figure 2 – Nuclear size correction to the Lamb shift as a function of nuclear charge Z.

0.2% at Z = 90 for the charge distribution employed in the NIST work, or by the uncertainty in the measured charge radius of the nucleus which is relatively large in some cases. (P. Mohr).

■ **Compact Formula for Electron Impact Cross Sections.** Both in the modeling of atoms in plasmas and the modeling of energy deposition by charged particles in matter, cross sections for excitation and ionizations of atoms and molecules by electron impact play a central role. The data needed cover a wide range of incident energies and many different types of excitations and ionizations. To facilitate the handling of a huge amount of cross section data, fitting formulas are preferred over voluminous numerical tables. Existing fitting formulas are either too cumbersome or limited in the range of incident energies for which such formulas are reliable. A new compact formula that requires only four fitting parameters has been developed and successfully applied to many excitation and ionization cross sections of light atoms and ions. The formula takes advantage of an earlier theoretical analysis that identified analytic dependence of cross sections on the incident energy. The new formula provides excellent fits near excitation and ionization thresholds, a traditionally difficult region for fitting formulas, and will enable one to accurately condense a large volume of cross section data in the literature for modeling studies. (Y.-K. Kim)

■ **Improving UV Lithography for Semiconductor Manufacturing.** We are collaborating with the Radiometric Physics Division on a development project funded by the SEMATECH consortium. This project addresses the problem of making accurate measurements of the ultraviolet (UV) radiation used in integrated circuit manufacturing. Photolithography, the use of UV light to make patterns on semiconductor wafers, plays an important part in the manufacturing process. The very bright light sources used decline continually in output, yet the UV dose to the semiconductor wafers must be accurately controlled, to about 1%, for successful etching of the fine patterns required. Moreover, the more recently designed instruments use light sources emitting wavelengths near 250 nm, shorter than those used in older instruments. This enables the etching of finer, more dense patterns necessary for faster and more powerful circuits for computers and other applications.

We are making significant improvements on our earlier developed prototype spectroradiometer to increase its effectiveness. Greater sensitivity, an expanded wavelength range and higher accuracy are being attained. Such spectroradiometers will ultimately be made an integral part of the manufacturing instruments. We are also working on a calibration unit, consisting of an additional spectroradiometer and a light source, to be used in calibrating the spectroradiometers on the manufacturing instruments. The accurate measurement and control of UV exposure in semiconductor manufacturing should result in more competitive products from U. S. semiconductor companies. (J. M. Bridges)

■ **Characterization of the GEC RF Reference Cell.** Differences in processes for "identical" plasma reactors constitute one of the major problems plaguing efficient use of multimillion dollar processing systems in the semiconductor industry. To address this issue the Gaseous Electronics Conference (GEC) RF Reference Cell has been developed and devoted to test ideas that would lead to possible control methods for processing plasmas in the semiconductor industry. Approximately 10 research groups in the U.S. decided to create this single common experimental platform and perform identical experiments to establish uniform methods to transfer reference measurements to other similar, but not identical systems.

Once the "simpler" problems of exactly defining and realizing voltage, current and phase had been resolved, it was decided that other diagnostic and reference measurements would be performed by participating laboratories. Energy distributions of both electrons and ions were identified as key parameters in the physics of the plasma process. Several different methods were chosen to investigate these parameters, among them energy analyzed mass spectrometry, optical emission spectroscopy, laser spectroscopy, and electric probe measurements. It was decided that nondestructive optical emission spectroscopic measurements would be one of the common methods, since several laboratories were set up to perform these measurements, especially our Division at NIST. Our optical emission measurements have laid the groundwork for a sensitive diagnostic (or possible process control) to determine the effects on plasma processes of small admixtures (impurity levels) of another species.

Figure 3 shows the profile of the H_α spectral line demonstrating a two-component (narrow spike vs broad base) energy distribution of hydrogen atoms. Since the profile widths and the relative intensities of the two components are sensitive to gas admixtures, these features could be used as an indicator of impurity effects on the plasma.

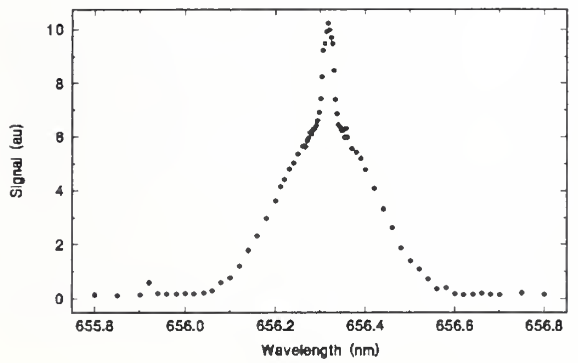


Figure 3 – Profile of the H_α spectral line.

Another contribution we made to the investigation of plasma process control measurements was the testing of electric probes to determine electron energy distributions. This is a joint project with the Process Measurement Division, Chemical Science and Technology Laboratory. Electric probes have long been used in low-density dc plasma discharges to determine electron temperatures, densities and energy distributions. Their application to rf plasmas was thought to be straightforward, but it was found with two commercial probes that the results obtained in an rf plasma were not reliable. Investigations continue with probes compensated for an rf applied voltage. (J. Roberts)

■ **Quantum Motion of Trapped Particles.** Earlier work in our group had demonstrated that atoms were trapped in the sub-wavelength-size potential wells formed by the interfering laser beams used in laser cooling. In new, higher resolution measurements, we have seen the quantization of the motion of atoms so trapped. By observing the spectrum of light emitted by the trapped atoms, using a high-resolution heterodyne spectroscopic technique, we can determine the nature of the atomic motion. A radiating atom trapped and oscillating in a potential well exhibits a phase-modulated spectrum with sidebands at the oscillation frequency. From the size and spacing of the sidebands, we determine the stiffness of the potential well and the degree of confinement. A non-classical feature, an asymmetry in the sidebands (see Fig. 4), arises from the thermal distribution of the population in the quantized energy levels of the trap. We find that at least half of the atoms can be in the quantum ground state of the trap, with a spatial spread of only 1/15 the wavelength of the light. (W. Phillips)

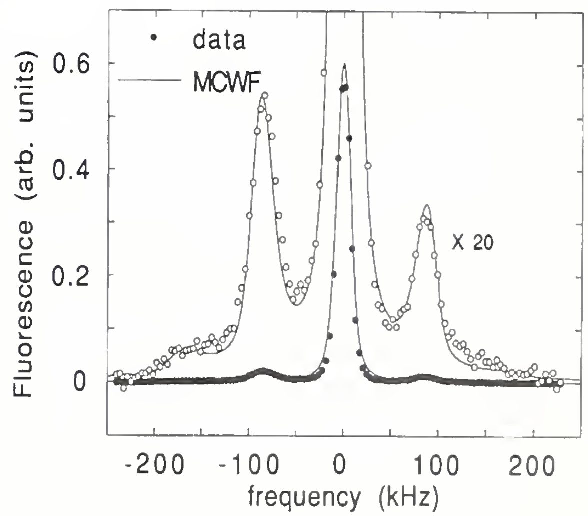


Figure 4 – The experimental data and theoretical prediction of the Monte Carlo Wavefunction Technique (MCWF) for the spectrum of light emitted by rubidium atoms confined in the optical potential wells of a standing wave laser field.

■ **Monte Carlo Wavefunction Technique.** Quantum optical problems involving the interaction of radiation with atoms, along with dissipation due to spontaneous emission, are treated theoretically using density matrix techniques. Because of coherence-destroying dissipative processes, it is not possible to write a wavefunction for such a system. Unfortunately, the calculational difficulty of manipulating the density matrix of a complex system can be overwhelming. The Monte Carlo Wavefunction (MCWF) technique allows the computationally simpler wavefunction to be used, while retaining all the features of the dissipative system. In collaboration with a group at the University of Colorado, we have used the MCWF technique to calculate the emission spectrum of laser cooled and trapped atoms (Fig. 4), obtaining remarkably detailed agreement between our experiment and the theory. (P. Lett)

■ **Cooling and Trapping Metastable Xenon.** Metastable xenon (Xe*) is a promising candidate for a laser cooled optical frequency standard. It was predicted that it should be easy to cool and trap using lasers, but this had never been demonstrated. We have now laser cooled an atomic beam of Xe*, trapped and concentrated it in a magneto-optical-trap (MOT), and have begun to measure some of its properties. Naturally occurring Xe has nine stable isotopes, some present at only 0.1% abundance. Each of these isotopes has been selectively trapped, and a measurement of the laser frequency needed to trap each isotope has been used to determine the isotope shift of the atomic energy levels with substantially improved precision over published values. The trap density is high enough that Penning ionization collisions between trapped atoms are easy to study and we anticipate studies of this process in the heretofore unexplored regime of ultracold temperatures. (S. Rolston)

■ **Curved Atomic Mirror.** During the past several years experiments in Moscow and at Stanford showed that atoms could be reflected from a dielectric surface having an evanescent light wave. The evanescent wave arises from a laser beam that is totally internally reflected from inside the dielectric. All of the early experiments were done with flat surfaces. We have succeeded for the first time in bouncing atoms from a curved, concave, evanescent-wave mirror (Fig. 5). Atoms laser cooled and confined in a magneto-optic trap are released so they fall onto a curved substrate. A laser beam, properly detuned in frequency, is internally reflected from the inside of the dielectric substrate. We have observed atoms dropped onto this mirror to bounce two times. We are now working to improve the performance and see more bounces, creating a new kind of trap for the atoms in which the evanescent wave and the gravitational field work together to confine the atoms. (K. Helmerson)

■ **Molecular Spectroscopy with Cold Atoms.** Sodium atoms irradiated with resonance radiation can undergo the associative ionization reaction, producing a Na_2+ molecule after absorbing two photons. At ultracold temperatures, the process can involve passing through an intermediate, excited state of Na_2. By trapping cold Na atoms in a magneto-optical-trap, then turning the trap off and irradiating the atoms with a single laser beam, we can perform photo-associative-spectroscopy, in which the production rate of Na_2+ is used to detect resonances corresponding to bound states of the intermediate molecular potentials. We have seen such structure, and have identified a previously overlooked process whereby the ground hyperfine structure of the atoms mediates a resonant enhancement of the rate of ion production. Photo-associative spectroscopy should allow detailed studies of the vibrational states belonging to potentials not normally accessible by traditional spectroscopic means. (K. Helmerson, P. Lett, W. Phillips, S. Rolston)

FUTURE DIRECTIONS

■ **Atomic Data Production.** We will continue the production of high-accuracy atomic structure data in several ways: We will explore experimentally and theoretically the structure of very highly stripped atomic ions where relativistic and QED effects are significant. Our electron beam ion trap (EBIT) facility will be operational during 1993 and we will start soft x-ray and extreme UV observations of very highly stripped ions. We will also continue to use major national

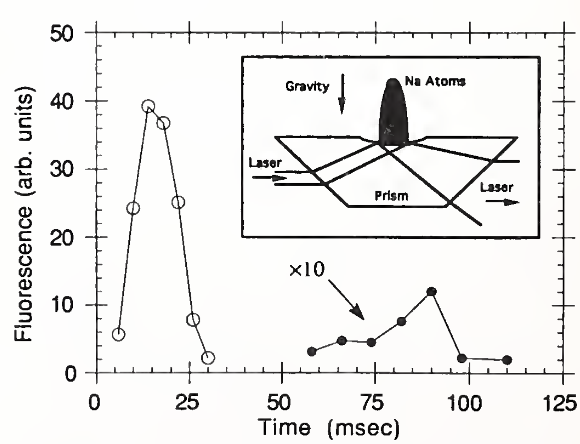


Figure 5 – Laser cooled and trapped sodium atoms are released 4 mm above a concave mirror for atoms, which uses the evanescent field from total internal reflection of a near resonant laser beam to reflect atoms (inset). The two peaks, in the fluorescence from the atoms that return to the initial drop position as a function of the length of time when the laser light for the atomic mirror is on, indicate that the atoms have bounced twice.

plasma facilities (TEXT Tokamak and the Rochester GDL Laser). On the theoretical side, we have developed sophisticated fully relativistic atomic structure programs which have all major QED corrections built in, and we plan to test these against observed data and identify systematic trends. We will especially explore the effect of core polarization potentials in atomic structure codes to make these more reliable for neutral and lightly charged ions.

■ **Laser Spectroscopy.** We will continue our high accuracy laser-spectroscopy observations for few-electron neutral atoms. These measurements test the advanced QED calculations that have been recently developed at several institutions.

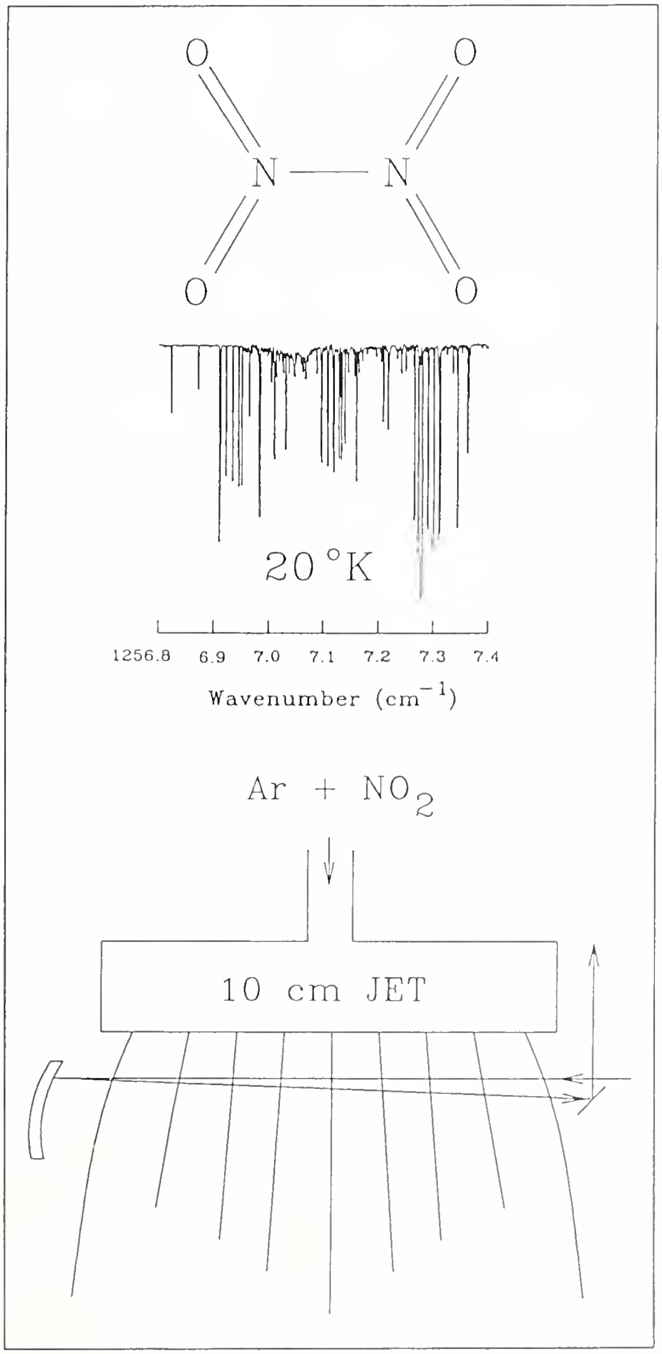
■ **Critical Atomic Data Compilations.** Our critical data compilation work is proceeding vigorously on tabulations of spectroscopic data for light elements of atomic numbers 1 through 20 and on the establishment of a comprehensive spectroscopic database. Our new tabulations will contain significantly more accurate as well as much more comprehensive data than the current NIST tables which have been the standard reference data works since the 1960s.

■ **Laser Cooling.** In our laser cooling work, we will further improve atomic fountains as the next generation atomic clocks, in both the microwave and optical domains. We will study new methods of molecular spectroscopy enabled by the ultracold temperatures achieved with laser cooling. We will also explore elements of atom optics such as coherent beamsplitters and laser-mirror reflectors.

■ **Plasma Diagnostics.** In the diagnostic work on industrially applied plasmas we will pursue nonperturbing approaches which utilize atomic radiation to probe these low temperature discharges. We will compare ion energy distributions using optical emission spectroscopy and energy analyzed mass spectrometry. Also, spectral radiation measurements will be utilized for space and time resolved analyses of the plasma conditions and particularly for determining the important concentrations of excited atoms and ions.

■ **VUV Source Radiometry.** In the area of VUV radiometry with plasma sources we are working on several improvements in our present array of sources and the addition of a new source. We see a continuing strong interest in this work by

MOLECULAR PHYSICS DIVISION



Overleaf

Infrared Spectrum of N_2O_4. The new fast-flow slit-jet spectrometer at NIST has been used to unravel the infrared spectrum of the atmospherically important N_2O_4 chemical species.

MOLECULAR PHYSICS DIVISION

MISSION

The Molecular Physics Division uses advanced spectroscopic measurement methods in the time and frequency domain and modern computational techniques to attack fundamental and applied molecular problems in physics, chemistry, and the interdisciplinary area between them. The Division provides:

- critically evaluated reference spectroscopic data on molecular species of importance in environmental and climatic concerns, chemical reaction mechanisms, and planetary and interstellar chemistry,
- experimental data and theoretical models for determining and predicting fundamental properties, energetics and internal dynamics of stable molecules, molecular complexes, and reactive species (ions and radicals),
- state-of-the-art data and models on ultrafast molecular processes, intramolecular dynamics, energy transfer in dilute and condensed phase systems, and molecule-surface interactions, and
- advanced theoretical models of atomic collision and molecular dissociation phenomena, especially as influenced by intense laser fields or by ultra low temperature.

Though the problems currently attacked bear the mark of fundamental investigations, all of them are pursued either in direct response to the needs of other government agencies, industry, or as long-term research projects to establish experimental or theoretical databases for newly emerging technologies, as well as to meet the contemporary challenges implied in the mission statement of NIST, newly reformulated in the Omnibus Trade Bill of 1988.

ORGANIZATION

The Molecular Physics Division employs approximately 20 scientists organized into three groups having different technical directions. The groups are High Resolution Spectroscopy, Molecular Dynamics, and Molecular Theory. Each has a group leader responsible for the technical activities of the group. The Division has an active program of collaborative research with guest researchers from other institutions, with 16 guests who visited for one month or longer. Projects involving molecular dynamics at surfaces is done in collaboration with scientists of the Surface and Microanalysis Division of the Chemical Science and Technology Laboratory.

CURRENT DIRECTIONS

■ **High Resolution Molecular Spectroscopy.** Work in the High Resolution Spectroscopy group involves experimental and theoretical application of molecular spectroscopy for characterizing gas phase molecules, primarily in the infrared and microwave spectral regions, and the development and application of new experimental techniques for high resolution spectroscopy. The emphasis of these studies is in the applications of this expertise to problems in structural chemistry, atmospheric chemistry, chemical analysis, radio astronomy, characterization of novel molecular species, e.g., complexes, ions, or radicals, and spectral data evaluation.

■ **Microwave and Infrared Spectra.** The High Resolution Group employs experimental microwave and infrared spectral methods on stable molecules and weakly-bound molecular complexes to determine chemical structures, potential energy surfaces, internal motions, reaction coordinate geometry, and reaction mechanisms. Theoretical studies of internal motions provide Hamiltonians required for modeling large-amplitude tunneling motions. Experimental laser measurement and analysis of properties affecting line-broadening for modeling atmospheric observations are provided to support the NASA Upper Atmosphere Program relating to chemical cycles identified in ozone destruction. Infrared spectral measurements of important atmospheric constituents in chemically reactive cycles are obtained for interpretation of atmospheric measurements. Detection and spectroscopic characterization of intermediates in chemical reactions provide the basis for identifying them in other environments, e.g., plasmas, combustion chemistry, chemical vapor deposition (CVD) processes and interstellar clouds. These species are the carriers of a wide variety of important chemical processes; without their participation, the reaction would stop. Because many of them react extremely rapidly, specialized techniques such as matrix isolation sampling and Fourier transform microwave spectroscopy must be used in order to detect them.

■ **Critically Evaluated Molecular Data.** Critically evaluated data on rotational, vibrational, and electronic energy levels of selected types of molecule (e.g., free radicals, molecular ions, interstellar species) are developed for use by the scientific and industrial communities. The data evaluation efforts are supported by NIST's Standard Reference Data Program and disseminated through publications in J. Phys. Chem. Ref. Data.

■ **Vibrational Energy Transfer on Surfaces.** Catalysis on metals and chemical vapor deposition on semiconductors are related to vibrational energy transfer (VET) between a molecule and a surface. VET rates influence sticking, desorption, surface mobility, reactivity, and surface vibrational spectroscopies. Sub-picosecond laser visible pump/infrared probe experiments are used to obtain time and frequency resolved spectra of vibrationally excited molecules on a surface. Specifically, the time for the low frequency (1.8 THz = 60 cm^{-1}) frustrated translation mode of an ordered monolayer of CO on Pt (111) to couple to hot electrons and hot phonons in the metal was determined. These experiments provide the first useful estimates for these coupling strengths.

■ **Bimolecular Reactions in Unrestricted and Restricted Collision Geometries.** Time-resolved and quantum-state-resolved observations of elementary reactions provide an atomic-level description of forces acting in molecules undergoing chemical transformations. For the collisional $O(^1D) + H_2O \rightarrow 2OH$ reaction, we have measured the quantum states and velocities of geminate pairs of OH fragments produced in individual reactive collisions. The state resolution is unprecedented, and the results challenge theoretical description of simple chemical events. We are also studying the $O(^1D) + H_2O \rightarrow 2OH$ reaction (and the analogous $O(^1D) + CH_4 \rightarrow OH + CH_3$ reaction) with reagents in restricted orientations, by photoinitiating the reactions in $O_3 \cdot H_2O$ and $O_3 \cdot CH_4$ clusters. This enables us to associate certain product channels with particular reaction geometries, and to measure lifetimes of intermediate species formed during the reactions with 100 fs time resolution. Surprisingly, in the case of $O_3 \cdot H_2O$, the dynamics are profoundly influenced by the third body (O_2) produced in the cluster reaction. The O_2 draws away most of the energy released in the reaction. Such termolecular effects must be ubiquitous in chemistry, but their dynamics have never been characterized.

■ **Femtosecond Transient Infrared Spectroscopy.** Identification of ultrafast processes in ambient and elevated temperature condensed-phase systems is key to developing detailed mechanistic and theoretical models of photochemical bond cleavage, product formation rates and vibrational energy dynamics. These processes are now being studied in the Molecular Dynamics Group by applying novel transient infrared methods. A unique broadband infrared laser spectrometer system using femtosecond laser pulses and rapid CCD detection electronics has been developed which possesses 200 fs time resolution and high spectral resolution in the 3–5 μm spectral region. By applying a single-shot normalization technique to collect simultaneous excited and reference spectra, unprecedented sensitivity and rapid spectral acquisition times have been achieved. Previously unobserved mono-carbonyl photoproduct formation rates for metal-dicarbonyl species in dilute solution are being determined with this apparatus.

■ **Theory of Cooled and Trapped Atoms.** The Molecular Theory Group has established a theoretical program to develop predictive models for understanding and interpreting the unique and novel physics of the collisions of laser cooled and trapped atoms at temperatures below 1 mK. This supports the NIST program in use of laser cooled atoms for improved time and frequency standards. State-of-the-art numerical implementations of quantum wavefunction methods are used to do calculations. Analytic approximations based on these are used to interpret the results. A completely new theory based on quantum density matrices and optical Bloch equations is being developed to treat new features of these unusual collisions.

■ **Dissociation and Ionization by Intense Lasers.** The dissociation and ionization of molecules by short extremely intense pulses of laser light has been studied at several laboratories outside of NIST. Theoretical models are being developed to interpret such experiments and to make predictions which can be tested by new experiments. New phenomena such as bond softening and trapping of vibrational populations are predicted when a molecule is irradiated by pulses of intense light. Expertise in applying time-dependent quantum wavefunction methods is being developed in order to attack these problems.

■ **Physical Understanding from Wavefunction Analysis.** Although quantum scattering calculations can be successfully applied to a variety of atomic and molecular dynamical and spectroscopic phenomena, complex numerical calculations often do not unmask simple underlying physical pictures. For this reason tools are being developed for analyzing and projecting physical insight from the analytic structure of multichannel quantum scattering wavefunctions. These methods are being applied successfully to problems in molecular dissociation, energy transfer collisions, spectral line shapes, and ultracold collisions.

■ **Efficient Molecular Population Transfer**. The rapid transfer of the population of one molecular level to another with 100 % efficiency is a highly desirable goal. Theoretical studies are being carried out to show how methods based on adiabatic rapid passage induced by optical pulses can achieve such a result. Both stimulated Raman and short-pulse frequency chirping methods are being investigated, with promising results. Such methods can be used to align or orient molecules, and also have potential applications as beam splitters for atom interferometers.

HIGHLIGHTS

■ **Infrared Laser Spectra of N_2O_4 and N_2O_3: Dimers of Important Atmospheric Molecules**. The infrared spectra of two important N_xO_y species, the dimer of NO_2 (N_2O_4) and the mixed dimer of NO and NO_2 (N_2O_3), have been examined. Spectra were recorded using a newly constructed diode-laser molecular-beam spectrometer, in which the dimers are formed by coexpanding NO and NO_2 gas mixtures with argon through a 10 cm long by 25 μm wide slit nozzle. In the resulting molecular beam the molecules are rotationally and vibrationally cold, with a measured rotational temperature of 20 to 50 K. The molecular beam is interrogated with a frequency-tunable diode laser. The cold molecular beam conditions dramatically simplify the spectra, making analysis possible while still yielding a high signal-to-noise ratio. The spectra have been analyzed to obtain accurate spectroscopic constants and precise structural information. For N_2O_4 we find a N–N bond length of 1.753 Å, in agreement with electron-diffraction measurements. The observed bond length is intermediate between a van der Waals separation and a covalent bond. In N_2O_3 a number of random small perturbations are present (matrix elements $< 0.03\ cm^{-1}$), which arise from coupling of the normal-mode vibration to high-order background combination vibrations involving the torsional coordinate. (J. L. Domenech, A. M. Andrews, S. P. Belov, G. T. Fraser, and W. J. Lafferty)

■ **Product State Correlations in the Reaction of $O(^1D)$ and H_2O in Bimolecular Collisions and in $O_3{\cdot}H_2O$ Clusters**. The $O(^1D) + H_2O \rightarrow 2OH$ reaction has the intriguing property of producing two chemically identical OH fragments with distinctly different histories, and the nature of trajectories which produce products has been a topic of considerable interest. For example, there has been much speculation about the existence of intermediate conformations like HOOH or OHOH. Interest in this system also derives from its role in combustion and atmospheric chemistry. As it happens, techniques used to measure OH concentrations in the atmosphere require precise knowledge of the dynamics of this reaction. In order to characterize the potential energy surface for this reaction, D. S. King, M. P. Casassa, and colleagues have investigated the dynamics of the photoinitiated reaction of $^{16}O(^1D)$ and $H_2{}^{18}O$, occurring as a bimolecular reaction in $O_3 + H_2O$ mixtures, and triggered in $O_3{\cdot}H_2O$ clusters. In these experiments, laser pulses (266 nm) photolyze O_3 to produce $O(^1D) + O_2(a^1\Delta_g)$. In the ensuing reaction,

$$^{16}O(^1D) + H_2{}^{18}O \rightarrow {}^{16}OH + {}^{18}OH + 118\ \text{kJ/mol}$$

the isotopic labelling enables us to distinguish between the newly formed "new" ^{16}OH and the residual "old" ^{18}OH fragment. Using laser induced fluorescence (LIF), we measured rotational, vibrational and fine-structure state distributions of the OH fragments. Fragment velocities were determined by measuring their Doppler-shifted LIF spectra. The results provide a level of dynamical detail that is unprecedented in the experimental description of bimolecular reactions that produce molecular products. The experiments have sufficient resolution to yield directly the correlations between energy states of the pairs of geminate OH products produced in the reaction. Previously, this type of information has only been inferred from statistical analyses of product state distributions.

The energy released in the reaction appears in OH product vibration (27%), rotation (34%), and translation (39%), and most of the vibrational and rotational energy is carried by the "new" OH fragment. The most intriguing observations are that the scattering directions of the fragments, their rotational and vibrational energies, and their translational energies are strongly correlated. The results are at odds with simple statistical and kinematic models of the reaction, indicating the primacy of the interatomic forces in directing the reaction. We see that most "new" OH molecules are scattered in the direction of the incident O-atom velocity. Those which have relatively little internal excitation are produced with geminate "old" OH fragments scattered in the opposite direction with high internal excitation. New OH molecules that are scattered at wider angles tend to have higher internal excitation and are paired with old OH fragments with low internal energy. The results indicate that the reaction is quite direct, any intermediate formed in the reaction persists for no longer than 90 fs, and no particular intermediate conformation is preferred.

Since the $O(^1D) + H_2O \rightarrow 2OH$ bimolecular reaction is direct, we expect the dynamics of the reaction initiated in the $O_3{\bullet}H_2O$ dimer to be affected by the restricted reaction geometries imposed by the cluster structure. In the cluster, photolysis of cluster-bound O_3 ejects $O(^1D)$ atoms so that the initial $O(^1D) + H_2O$ trajectory resembles an O–HOH fly-by or stripping motion, and not an intimate collision. Initially we presumed that the dynamics would comprise a subset of the correlated dynamics observed for the collisional experiment. Instead, the third body in the cluster reaction (O_2) greatly perturbs the reaction dynamics. The rotational, vibrational, and kinetic energies of the OH cluster fragments are far lower than those of the products of the collisional reaction. The third body must carry a significant amount of the energy produced in the reaction, possibly in the form of electronic excitation. This characterization of termolecular dynamics is a significant achievement. Termolecular events must be important in condensed phase chemistry, and in chemistry at high pressures, but are poorly understood. This work is performed with support from the AFOSR High Energy Density Materials Program. (D. S. King and M. P. Casassa)

■ **Characterization of a New Class of Compounds Being Considered for Use as Alternative Refrigerants.** The phasing out of the chlorofluorocarbons (CFCs) commonly used as refrigerants, solvents, and propellants for the last 50 years is causing the search for environmentally acceptable alternatives to be accelerated. One of the families of compounds that are being considered for use as alternative refrigerants is a class of partially fluorinated ethers. In the search for new refrigerants, no one compound has been found to be satisfactory in all respects. Therefore, mixtures of various compounds are being considered. Mixtures offer the potential of tailoring refrigerants in a variety of ways: modifying vapor pressure, changing lubricant solubility characteristics, changing specific heat, and altering flammability ranges. However, the number of mixtures possible is so large that measurement of all possibilities is impractical. One must rely on a small number of wisely chosen measurements and combine these with the best theoretical modeling techniques to predict the necessary properties.

The properties of hydrocarbon and halogenated hydrocarbon mixtures have been found to have strong correlations with the permanent electric dipole moments and the molecular polarizabilities of the constituent compounds. The electric dipole moment has been used for predicting the mixture equation of state, a feature that has been incorporated into NIST Standard Reference Database 23 "NIST Refrigerant Properties Data Base." Currently, most measurements of the dipole moment and polarizability are carried out on the vapor. The electric dipole moment is obtained by measuring the dielectric constant over a range of temperatures. While this is the method of choice, because the measurements can be made fairly quickly for most compounds, complications can arise in these measurements that make it difficult to interpret the results on a quantitative basis. This occurs for the compounds that exist as mixtures of many conformational isomers, whose relative concentration is a strong function of temperature. Since the dipole moment is a strong function of the conformation of the molecule, the dielectric constant of the bulk refrigerant changes in a complicated way as the temperature of the refrigerant is changed, i.e., as the relative fraction of the conformers change.

When a compound has the possibility of existing as several steric conformations (as is the case with the partially fluorinated ethers), dielectric measurements are insufficient to determine the dipole moments and relative abundances of the various conformers. Unique interpretation of the dielectric measurements is possible only if the dipole moments and the relative abundances of the various conformers present can be independently obtained.

In order to establish some benchmarks to aid these modeling calculations, R. D. Suenram and F. J. Lovas studied two members of the family of fluorinated ethers in detail, namely, CF_2HOCF_2H and $CF_2HOCH_2CF_3$, and have determined the lowest energy conformation and measured the electric dipole moments of the lowest energy conformer for both compounds. This is important information for use in modeling of the mixture equations of state for this series of compounds since each conformer makes an individual contribution, which is strongly dependent on the dipole moment, to the free energy of the mixture. Modeling calculations which incorporate this new information are now feasible and are much more accurate than those which used estimated values for dipole moments and conformer geometries. (R. D. Suenram and F. J. Lovas)

■ **Collisions of Ultracold Atoms.** Rapid advances in laboratory techniques for laser cooling and trapping of neutral atoms at temperatures below 1 mK offer many new opportunities to science and technology, such as greatly improved atomic clocks, optical manipulation of atomic beams, and the development of atom interferometers. Collisions of laser cooled and trapped atoms exhibit new and unusual physics which must be understood in order to make optimal use of this new technology, since collisions strongly affect cold atomic sources or interfere with precise frequency measurements in atomic clocks. P. Julienne and F. Mies of the Molecular Theory Group have done pioneering research in the unique physics of these collisions at temperatures below 1 mK, supported in part by a NIST Competency Program and in part by the Office of Naval Research.

Cold collisions in the absence of light are affected by the onset of special quantum effects. We have carried out calculations on trapped Rb atoms to illustrate the sensitivity of collisions to subtle details of the molecular potentials and to show the important contribution molecular spectroscopy can make to find needed parameters. Cold collisions of laser excited atoms are sensitive to the interatomic potentials at extremely long range and are strongly influenced by excited state radiative decay during the long time of the collision. Such collisions are "open" quantum collisions, and new theoretical methods based on density matrix rather than wavefunction methods are being developed which treat dissipation during a collision.

We have applied new optical Bloch equation methods to several types of collisions of laser cooled Na atoms. We find reasonable agreement with new measurements in magneto-optical traps on collisions which heat the trapped atoms so they are lost from the trap. A detailed molecular model of the associative ionization of two excited Na atoms has been produced that allows us to calculate the effect of molecular bound states on the associative ionization rate. Ultracold associative ionization is a multistep molecular process which we call photo-associative ionization (PAI). The PAI spectrum, that is, the ionization signal versus the frequency of one or more colors of exciting light, is a sensitive probe of very long range interactions between two atoms, and we have calculated the PAI spectrum for several types of experiments.

In general, we expect photoassociation spectroscopy of ultracold atoms to be an important new tool for measuring long range interactions for a variety of species that can be laser cooled. This work has been carried out in collaboration with Yehuda Band, Ben-Gurion University, Israel, and Robert Heather, working under contract with NIST. (P. S. Julienne and F. H. Mies)

■ **Large Amplitude Motions and Vibrational Couplings in Molecules**. To assess the importance of torsional vibrations and other large amplitude motions in intramolecular vibrational relaxation (IVR) we have examined the infrared spectra of a number of molecules with large amplitude motions using an electric-resonance optothermal spectrometer (EROS). The molecules have been studied at low levels of excitation ($\sim$ 1000 cm^{-1}) where the density of vibrational states is sufficiently small that the normal mode identities of the vibrations are clear and the interaction matrix elements are not diluted by the multitude of couplings seen in high-density-of-states regimes. Attempts have been made to measure interaction matrix elements between various vibrations and the large amplitude mode. Knowledge of these couplings are important since large amplitude vibrations are the main contributor to the large state density occurring at higher energies where IVR occurs. Molecules studied include CF_3CH_3, CH_3CHO

(acetaldehyde), $HC{\equiv}C{-}CH_2{-}NH_2$ (propargyl amine), $HC{\equiv}C{-}CH_2{-}CH_3$ (1-butyne), $CH_3{-}CH{=}CH_2$ (propene), $CF_3{-}CH{=}CH_2$, ethanol, and 2-fluoroethanol. The high resolution of the EROS spectrometer allows us to resolve torsional splittings which serve as a sensitive probe of the coupling of the normal-mode vibration to background vibrations differing in the number of quanta in the torsional coordinate. In the case of $CF_3{-}CH{=}CH_2$, resolved torsional splittings are used to observe a vibrational coupling involving an interchange of as many as eight vibrational quanta, four or five of which are in the torsional coordinate. (A. Ainetschian, A. M. Andrews, S. P. Belov, J. L. Domenech, G. T. Fraser, C. C. Miller, B. H. Pate, A. S. Pine, and M. Yu. Tretyakov)

■ **Highly Vibrationally Excited Molecules in Strong Electric Fields**. The dynamics of a molecule in a high-density-of-states regime in an external electric field has been investigated using a molecular-beam optothermal spectrometer. The $J = 0 \rightarrow 1$ transition of the acetylenic C–H stretch of propargyl alcohol, $HC{\equiv}CCH_2OH$, was excited in a homogeneous electric field (0 to 25 kV/cm) using a tunable color-center laser. At zero-field the transition is broken into a multiplet of 4 components spread over ~ 2000 MHz, characteristic of intramolecular vibrational relaxation in the intermediate density-of-states regime (~ 60 states/cm^{-1}). The number of observed components grows nearly linearly with electric field, as the field destroys J and parity as good quantum number labels. At the highest field studied, 24 kV/cm, approximately 50 states are observed. The center of gravity of the ~ 2 GHz wide spectral feature moves ~ 2.5 GHz with electric field, which is just the amount predicted for a $J = 0 \rightarrow 1$ transition in a low density of states regime. However, each individual eigenstate moves substantially less. Instead, the spectral intensity appears to move over a picket fence of eigenstates frozen in by their mutual field-induced repulsions. The onset of this spectral rigidity occurs at field strengths which shift the spectral intensity on the order of $1/\rho$, where ρ is the vibrational density of states. This spectral rigidity is responsible for the absence of deflection by an inhomogeneous electric field of a molecule excited to a single eigenstate in a high-density-of-states regime. (G. T. Fraser and B. H. Pate)

■ **Spectroscopy of Atmospheric Molecules.** Doppler-limited and sub-Doppler spectra have been recorded of several heavy atmospheric species including acids, alcohols, aromatics and fluorocarbons in order to interpret their spectra and predict their atmospheric properties. This year, room temperature spectra of the $2\nu_3$ and $3\nu_3$ overtone bands of sulfur dioxide were recorded with a difference-frequency laser system. The $3\nu_3$ spectrum was used in identifying recently observed spectra of the atmosphere of Venus; the $2\nu_3$ band exhibited anomalously weak intensity and strong Coriolis mixing. Higher resolution and much lower temperatures were achieved in a molecular-beam optothermal spectrometer (MBOS) with which the fluorocarbons, CHF_2Cl and CH_3CF_3, were studied. In these molecular-beam studies, the hydrogenic stretching modes were probed with a color-center laser in the 3 μm region; and CH_3CF_3 was also pumped with a newly developed CO_2-sideband laser in the 10 μm region. The observed spectra have all been assigned and fit to high precision except for the highly perturbed CH stretch of CH_3CF_3. We hope to use microwave-infrared and infrared-infrared double resonance to unravel the 3 μm region. The 10 μm band of CH_3CF_3 exhibited significant torsional splittings and Fermi-resonant perturbers which will be described in the section on large-amplitude internal rotations.

The study of collisional lineshapes has continued with emphasis on the phenomenon of line mixing in heavily overlapped spectra. We have recorded self-, N_2- and Ar-broadened combination band Q branches in HCN and HCCH from the well-resolved Doppler limit at low pressures to the blended contours at atmospheric pressures using a tunable difference-frequency laser spectrometer. At low pressures, the broadening coefficients as a function of rotational quantum number J are independent of vibrational level and can be modelled successfully using an energy-corrected-sudden (ECS) approximation scaling law for self-broadened HCN and with simpler empirical energy-gap fitting laws for the other collision partners. No empirical collision dynamics model was found suitable for all cases. Line mixing, which is manifest as a non-additive superposition of Lorentzian lines, strongly affects the blended contours at higher pressures, and indicates that the coupling between lines varies from 30 to 64% of the collisional broadening. The decoupling presumably arises from collisional energy transfer to the other member of the l-type doublet not observed in the Q-branch transitions of these Π-Σ bands.

We have also studied self-, N_2-, O_2-, H_2-, Ar- and He-broadening of the Q branch of the ν_3

band of methane with the difference-frequency laser. A systematic dependence of the broadening coefficients of the tetrahedral symmetry species and order index is observed, with striking similarities for N_2, O_2 and Ar and for H_2 and He buffer gases. Dicke narrowing is evident at intermediate pressures, yielding an average narrowing coefficient and an optical diffusion constant for each buffer gas. Similar measurements have been made on the ν_1 band of ammonia, and the data are currently under analysis. The self-broadening coefficients are in excellent agreement with ground-state inversion measurements and are systematically 5 to 25% lower than calculated by Anderson theory, depending on K. (A. S. Pine, G. T. Fraser, and W. J. Lafferty)

■ **Infrared Spectra of Molecular Ions.** Working together with Guest Researchers Dr. Daniel Forney and W. Thompson, M. Jacox has obtained the infrared spectra of several small molecular ions trapped in solid neon. Because of the ubiquity of water and the fundamental importance of H_2O^+, special emphasis was placed on that system. Water molecules can rotate in the solid rare gases, and the rotational structure of the water absorptions in solid neon had not previously been studied. Therefore, a detailed assignment of these absorptions was made. Matrix shifts were much smaller than had previously been found for water trapped in the heavier rare-gas solids. In the ion production experiments, the bending fundamentals of both H_2O^+ and D_2O^+ appeared within a few cm^{-1} of the gas-phase band centers, and the two stretching fundamentals of H_2O^+ appeared approximately 1% below the positions of the corresponding gas-phase band centers. All three fundamentals of HDO^+ and the two stretching fundamentals of D_2O^+, for which gas-phase infrared absorption data are not available, were also detected. In other, related experiments evidence was obtained for a weak $H_2O{\cdot\cdot}H_2$ van der Waals complex. Infrared activity of the H_2 moiety and an approximately 10 cm^{-1} shift in the antisymmetric stretching fundamental of the H_2O moiety were associated with formation of this complex.

The formation of ions from several other small molecules was also studied. In experiments on NO_2, the previously assigned ν_3 fundamental of NO_2^- was extremely prominent, and the $(\nu_1 + \nu_3)$ combination band of NO_2^- was identified. The prominent ν_3 fundamental of NO_2^+ and the $(\nu_1 + \nu_3)$ combination band of NO_2^+ were also identified. Shortly after these experiments were completed, the first gas-phase spectroscopic identification of NO_2^+, achieved using three-color ionization, was reported in the literature. The results are in excellent agreement. In studies of the ionization of HCl, the infrared absorption of HCl^+ predominated, and weaker absorption of H_2Cl^+ appeared. When O_2 was added to the system, two infrared absorptions of the weakly bonded $O_2{\cdot\cdot}HCl^+$ complex were identified. Although in the gas phase the predominant product of the interaction of 16.6 eV radiation with either methylacetylene or allene is cyclic $C_3H_3^+$, in the neon matrix experiments deactivation of the initially formed ion led to the stabilization of a common $C_3H_4^+$ product in both systems. Experiments on the isoelectronic CH_3CN molecule led to the stabilization of several neutral and ionic products, including $H_2C=C=NH$ and CH_2CN^+. Finally, experiments on CF_4 and HCF_3 samples indicate that CF_3^+ is formed in significant concentration in both systems. In addition to the previously identified ν_3 absorption of that species, the out-of-plane deformation fundamental, ν_2, was observed. Moreover, evidence was obtained for the formation of F^-. (D. Forney, W. Thompson, and M. Jacox)

■ **Vibrational and Electronic Energy Levels of Small Polyatomic Transient Molecules.** The first upgrade of this computer-searchable database, designed for use with personal computers, was completed, and preparations are well along for the second upgrade. Critically evaluated data for the ground- and excited-state vibrational fundamentals and the electronic band origins of some 1440 molecules are presently included in the database. Users may search by molecule, by wavenumber range, or by wavelength range. A monograph which includes not only these data but also radiative lifetimes and rotational constants (A_0, B_0, C_0) is also in preparation. (NIST VEEL–Standard Reference Database #26, M. Jacox)

■ **Picosecond Measurement of Substrate to Adsorbate Energy Transfer.** In a joint research effort involving scientists in the Molecular Physics Division (J. C. Stephenson and E. J. Heilweil) and the Surface and Microanalysis Science Division (R. R. Cavanagh and T. A. Germer), picosecond lasers are being used to determine the rates and mechanisms for energy to flow from metal substrates to the vibrational modes of chemisorbed molecules. Such information is critically important to understanding chemical reactivity at surfaces since sticking, desorption, surface mobility and chemical reactions are activated by vibrational excitation. The coupling of optical radiation to surface reactions is receiving attention in the fields of catalysis, semiconductor processing, and solar energy conversion.

In these first experiments, carbon monoxide (CO) chemisorbed at monolayer coverage (i.e., $\Theta = 0.5$) on a clean Pt(111) crystal was studied because it is the adsorbate/substrate system best characterized by traditional non-time-resolved methods. Two laser pulses of about 0.9 ps (1 ps = 10^{-12} s) duration hit the crystal; one is a visible pump pulse, the other an infrared probe pulse which determines the energy content of the Pt and CO vibrational modes by absorption spectroscopy as a function of pump/probe time delay. Interpretation of this time-resolved spectrum yields the following information. The pump pulse excites the Pt substrate (initially at T = 150 K) creating hot electrons near the surface (penetration depth = 15 nm). These hot electrons initially have an elevated electronic temperature $T_e \approx 250$ K. In 1.6 ps the hot electrons equilibrate with the Pt lattice vibrations (phonons) giving $T_{lat} = T_e = 200$ K. The hot electrons and phonons then energize one of the four vibrational modes of the chemisorbed CO, specifically the frustrated translation mode at a frequency ν_4 = 1.8 THz (60 cm^{-1}). The temperature T_{ads} of this mode comes into equilibrium with T_e and T_{lat} in 2 ps. If the mode is excited only by the hot electrons, then T_e and T_{ads} have a coupling time of 2 ± 1 ps. If, instead, the mode couples only to the Pt phonons, then T_{lat} and T_{ads} have a coupling time less than 1 ps. On a longer timescale of 100 ps, the three coupled temperatures return to the initial value as heat diffuses away from the surface into the Pt crystal.

This low frequency frustrated translation mode, ν_4, is probed indirectly. It is known from static measurements that anharmonic coupling between ν_4 and the high frequency CO stretch mode ($\nu_1 \approx 2106$ cm^{-1}) causes the absorption of the latter to decrease in frequency with increasing population of ν_4 as $\nu_1 = \nu_1^0 - 2\ cm^{-1} \langle\nu_4\rangle$. The shift of ν_1 as a function of pump-probe time delay is measured, revealing the dynamics of energy flow to and from ν_4. These experiments provide the first useful estimates of these energy transfer rates, which are quite fast, comparable to the 0.6 ps vibrational period of the ν_4. The NIST group is now starting experiments on other systems of which the first is CO on Cu(100). The coupling strength between electrons and lattice phonons is a factor of 30 less for Cu than for Pt, and this should allow a very clear distinction between coupling of absorbate modes to lattice phonons and hot electrons. Also, this will enable direct comparison to calculations for CO on Cu being done by colleagues at AT&T Bell Labs and the University of California at Berkeley. (J. C. Stephenson, E. J. Heilweil, R. R. Cavanagh, and T. A. Germer)

■ **Broadband Femtosecond Infrared Spectroscopy of Solution-Phase Photochemistry.** A long-standing goal in chemical physics is to unravel the detailed mechanisms and energetics of complex molecular reactions. Of particular interest is the development of experimental methods to directly probe short timescale reaction dynamics of industrially and biologically relevant chemical processes. Towards this end, T. P. Dougherty and E. J. Heilweil have pioneered a novel infrared spectroscopic technique for directly monitoring energy flow in reaction intermediates and the appearance of photoproducts *in real* time with 200 fs (ca. 10^{-13} s) time resolution.

The method has been applied to studies of ultrafast events such as fragment ejection, product solvation and vibrational energy flow in photochemical reactions of inorganic metal-carbonyl species in room temperature solution. Metal carbonyls are important chemical species because they function as precursors in homogeneous catalysis and are used as models for surface heterogeneous catalytic processes. With the use of state-of-the-art femtosecond lasers, an intense ultraviolet pulse is absorbed by species such as $Rh(CO)_2(C_5H_7O_2)$ and $Co(CO)_2(C_5H_7)$ in dilute n-hexane, CCl_4, and chloroform solutions. The subsequent appearance of monocarbonyl products is detected with vibrationally and structurally sensitive time-resolved infrared spectroscopy. A broadband IR probe pulse tuned in the CO-stretching region of the spectrum (near 5 μm) interrogates the excited sample, is subsequently upconverted into the visible spectral region and dispersed onto a CCD multichannel detector. A second probe pulse, which traverses an unexcited region of the sample, is similarly collected so that shot-to-shot normalization yields 0.2% transmission change sensitivity (seven minute collection time) for each time-delayed spectrum. In this way, detailed spectroscopic "snapshots" of the time-dependent concentration changes of transient and product species are obtained.

In both molecules studied, ejection of a single CO fragment occurs, forming a fully solvated, thermally equilibrated, monocarbonyl species. The reaction appears to be complete in 10-15 ps for $Co(CO)_2(C_5H_7)$ in n-hexane but takes only a few picoseconds for $Rh(CO)_2(C_5H_7O_2)$ in the solvents examined. While the newly formed product species are comprised of many atoms and internal degrees of freedom, they show no evidence for being formed vibrationally hot. Studies are underway to determine the structural location and energy content of specific chemical bonds in the products before and during solvation, thus leading to a fundamental understanding of the reaction mechanisms of these and related molecules. (T. P. Dougherty and E. J. Heilweil)

■ **Vibrational Trapping and Suppression of Dissociation in Intense Laser Fields.** The response of molecules to very intense, short pulse optical frequency laser radiation has been of much experimental and theoretical interest recently. F. Mies, in collaboration with A. Guisti of the University of Paris, has predicted the unexpected suppression of photodissociation for short 150 fs laser pulses, and the associated trapping of molecules in coherent superpositions of vibrational states. Specifically, they calculated the dissociation of H_2^+ for a variety of wavelengths and a wide range of initial vibrational states. While low-v levels achieve 100% dissociation in the leading edge of the pulse, for high v there is the onset of stabilization, and significant population remains in bound vibrational states throughout the entire pulse. The dissociation is incomplete, and a coherent distribution of excited vibrational states is formed. The survival effect can be attributed to the trapping of portions of the initial vibrational wave packet in transient laser-induced potential wells. This suppression of dissociation is associated with that portion of the initial vibrational wave packet that is cut by an intensity-dependent avoided crossing of the field-dressed molecular states, and is lifted by the increasing field to higher energies. Population is "shelved" well away from the repulsive bond-softening potential which opens the system to rapid dissociation. Although calculations were only done for H_2^+, this dissociative stabilization is expected to be quite general. (P. S. Julienne and F. H. Mies)

FUTURE DIRECTIONS & OPPORTUNITIES

■ **Mechanistic Investigation of Energetic Materials.** Nitramine propellants are energetic chemical compounds containing nitro groups chemically bound to other nitrogen atoms, i.e., containing fragments of the form $N-NO_2$. RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine) and HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazine) are two of the most widely used propellants of this type, and considerable research exists on the macroscopic ignition and combustion properties of RDX and HMX. However, in order to optimize the use of RDX and HMX, as well as to devise improved propellants with related chemical structures, a knowledge of the microscopic ignition and combustion behavior of these propellants is required. With support from the Army Research Office, Division of Chemical and Biological Sciences, we will begin an investigation of unstable intermediates in RDX and HMX thermal decomposition processes, using conventional and Fourier-transform microwave (FTMW) spectroscopic methods. Microwave spectroscopy can determine with great certainty the chemical composition and structure of the intermediates. Thermal decomposition will be examined by three methods: (a) vaporization in a heated pulsed nozzle coupled to the FTMW spectrometer, (b) thermal pyrolysis of the vapor over a catalyst substrate, and (c) laser ablation from the surface of solid samples of the propellant and analysis by FTMW.

The unimolecular laser infrared multiphoton dissociation (IRMPD) photolysis decomposition

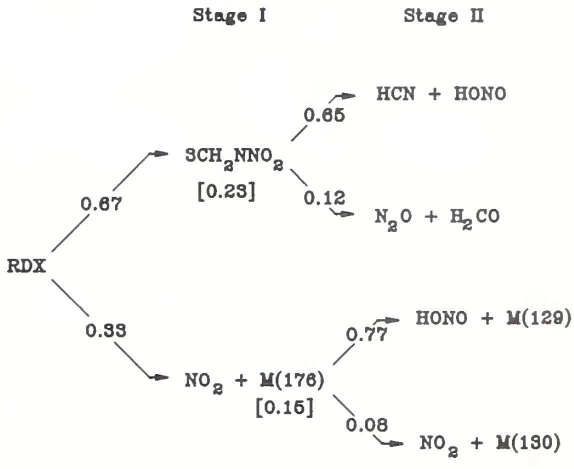


Figure 1 – Mechanism of RDX decomposition proposed by Zhao, X., Hintsa, E.J., and Lee, Y.T., *J. Chem. Phys.* **88**, 801 (1988).

scheme for RDX proposed by Zhao et al, determined through deconvolution of the time-of flight mass spectra, is illustrated in Fig. 1.

The dominant channel is a concerted triple fission of the RDX ring to produce three $CH_2N_2O_2$ (mass 74) fragments which were identified to be the $CH_2=NNO_2$ species. Zhao et al contend that the dissociation mechanism obtained in IRMPD experiments is the same as that in thermal decomposition experiments on other moderate size systems they have investigated. Our objective is to identify each of these product species, and any others which might be produced but not observed in other studies. Special emphasis will be to identify the triple fission product $CH_2=NNO_2$.

This research will have impact on three critical areas for energetic materials: (1) the validity of existing gas phase reaction mechanisms; (2) extension of reaction mechanisms to include binder chemistry; and (3) identification of new reaction mechanisms. (F. J. Lovas, R. D. Suenram, N. F. Zobov, and M. Yu. Tretyakov)

■ **Collisional Energy Transfer.** In our ongoing studies of collisional lineshapes for modeling atmospheric spectra, we have found that the phenomenon of line mixing or collisional interference provides new information about collisional energy transfer not available from line broadening measurements alone. We have observed in Q branches of linear molecules that rotationally inelastic collisions dominate the broadening but that significant decoupling exists due to cross-relaxation to other unspecified levels, presumably the vibrational parity (ℓ-doublet) partners. We plan to explore such collisional relaxation processes directly in the time domain by transient, state-to-state, pulsed-pump, cw-probe, laser double-resonance techniques. A new high-energy, transform-limited-pulse Nd:YAG laser system has been acquired for both stimulated Raman and nonlinear-optical infrared generation for high-resolution pumping of individual rovibrational levels of molecules. A color-center laser will be used as a probe. (A. S. Pine)

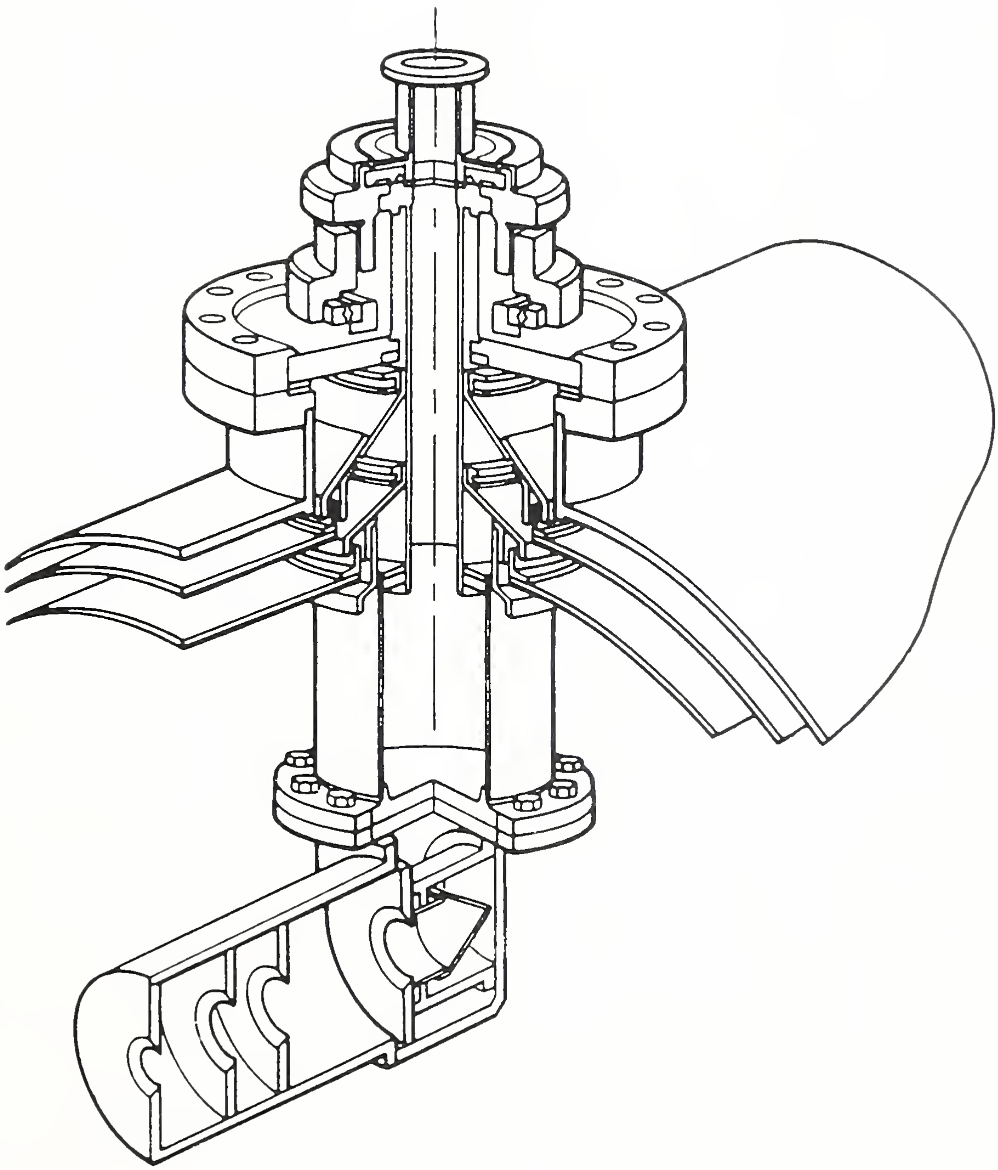
■ **Classically Forbidden Chemical Reactions.** The time-resolved and quantum-state-resolved dynamics of classically forbidden bimolecular reactions will be measured in the Molecular Dynamics Group. These experiments are novel because of the necessity to propel molecules over a reaction barrier in a controlled fashion. Control over reactive collisions between molecules will be achieved by using laser pulses to orient and direct molecules in space, and by exploiting weak intermolecular forces to configure molecules prior to reaction. An example is the $O(^3P) + H_2 \rightarrow OH + H$ reaction, where both products can be detected by laser induced fluorescence. Preparatory laser pulses will excite H_2 *via* Raman transitions to rotational and vibrational energy levels below the reaction threshold. Additional energy to overcome the reaction barrier will be deposited as kinetic energy in $O(^3P)$ atoms produced by photolysis of a precursor, such as O_2, using an ultraviolet laser pulse. The Raman step orients the H_2 molecules in space, while the photolytic step produces a directional, monoenergetic flux of $O(^3P)$ atoms. We can orchestrate end-on or broadside initial encounters with H_2, with reaction energies controlled by the wavelengths of the lasers. Further control over initial trajectories is possible using van der Waals forces to orient the reagents prior to the laser pulses. We will measure the disposition of energy in fragments (in the form of rotation, vibration, and translation), the direction of fragment velocity and angular momentum vectors in space, and correlations among these quantities. In the case of the cluster reaction, we can measure product appearance rates with 100 fs time-resolution. Results on $O(^3P) + H_2 \rightarrow OH + H$ will be especially significant because this system is a benchmark for *ab initio* methods, and its understanding is important in modeling combustion chemistry. (M. P. Casassa and D. S. King)

■ **Ultrafast Dynamics of Hydrogen Bond Cleavage and Photochemistry at Solid/Liquid Interfaces.** A broadband femtosecond infrared spectrometer developed in the Molecular Dynamics Group will be modified to generate intense IR excitation pulses (ca. 100 μJ, 200 fs duration) for studying proton transfer and hydrogen bond reactions. Solution-phase dimers of alcohols or model organic species for DNA base pairs will be examined for the first time to determine energy deposition dynamics and dissociation-reformation rates. Analogous studies of photochemically active, dispersed colloidal semiconductors will be initiated to identify transient species and mechanistic pathways in fuel-generating surface photo-redox reactions. (E. J. Heilweil and T. P. Dougherty)

■ **Development of Theoretical Methods.** The studies on ultracold collisions will continue along the directions already begun, building on existing accomplishments to predict and explain new experimental results. Fully quantum versions of our semiclassical optical Bloch equation methods will be developed for describing collisions coupled to a dissipative bath, with the expectation that these methods can be used for general dissipative collisions coupled to an environment. It is absolutely crucial to include the role of hyperfine structure in ground and excited state collisions, if we are to advance beyond relatively crude models. Understanding the hyperfine effects should enable us to show how to manipulate ultracold collisions optically, turning certain processes off or on. We will also carry out calculations of the photoassociation spectra in expectation of a new generation of experiments on Na and other species that probe the very long range molecular interaction potentials at distances of many hundreds of Bohr radii. We anticipate that an understanding of the novel physics of ultracold collisions will come about because of the interplay between theory and experiment. There is much similarity between the methods used to describe intense laser field effects in ultracold collisions and in intense field molecular photodissociation. Recently we have introduced explicitly the time-dependence of the laser into the photodissociation calculations, and have directly integrated the coupled time-dependent Schrodinger equation for the interacting system. We intend to continue to develop these methods. We will explore the possibility of manipulating ultracold atomic collision dynamics using time-dependent laser pulses to probe and control the course of a slow reaction. We will also continue development of analytic methods for interpreting and analyzing multichannel scattering wavefunctions. This work should lead to powerful new tools for understanding collisions and half-collisions. These methods factor quantum transition amplitudes into contributions from different zones of interatomic interaction, and establish the interconnections between zones. These methods have many uses in conventional and ultracold collision dynamics. One application will be to study the velocity dependence of atomic collision rates from conventional to ultracold collision energies. These methods can also be used to show the connections between wavefunction and density matrix methods. (P. S. Julienne and F. H. Mies) ▫

TECHNICAL ACTIVITIES

RADIOMETRIC PHYSICS DIVISION



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Absolute Cryogenic Radiometer. This electrical substitution radiometer measures optical power in terms of electrical power and is an absolute detector with flat response for visible to far-infrared wavelengths. It has been characterized to measure the irradiance at its aperture in the range from a few nW/cm^2 to 10 $\mu W/cm^2$ with less than 1% uncertainty. It is the absolute standard detector for cryogenic blackbody calibrations at the NIST Low Background Infrared (LBIR) facility. Recent users of this facility are aerospace contractors such as Rockwell International, Arnold Engineering Development Center of the U.S. Air Force, and Utah State University at Logan, Utah.

RADIOMETRIC PHYSICS DIVISION

MISSION

The Radiometric Physics Division of the Physics Laboratory is the primary unit within NIST for carrying out the basic mission of promoting accurate, meaningful, and compatible optical radiation measurements in the ultraviolet, visible, and infrared spectral regions. The Division:

- develops, improves, and maintains the national standards for radiation thermometry, spectroradiometry, photometry, and spectrophotometry;
- disseminates these standards by providing measurement services to customers requiring calibrations of the highest accuracy;
- conducts fundamental and applied research to develop the scientific basis for future measurement services in optical radiometry.

To accomplish these goals in a responsive manner, the Division staff works closely with industry and other government agencies in developing programs to meet specific needs. The Division maintains a broad range of fundamental and applied research programs, calibration services, and standard reference material (SRM) production to accommodate the technical needs of the radiometric community and to provide leadership in identifying future needs. Additionally, the Division staff is active in professional societies and participates in the activities of the Council on Optical Radiation Measurements (CORM) and the International Commission on Illumination (CIE). CORM and CIE are technical organizations that include a strong industrial constituency. These organizations provide the Division insight on identifying the emerging needs of American industry which require satisfaction in order to support the growth of quality manufacturing efforts. Meeting some of the goals requested will assist American industry in maintaining a competitive posture in the world market.

ORGANIZATION

The Division employs approximately 30 scientists, engineers, and technicians, and maintains a balanced mix of research, development, and measurement services. It is organized into four groups and operates under a project structure with collaborations across group lines. Each of the projects has an assigned leader who is responsible for planning and accomplishing the technical objectives of the project. The project teams in the Division interact and work jointly on various tasks, sharing resources to achieve common goals. For example, the staff of the Detector Applications Project in the Detector Metrology Group works with the staff of most other projects in the Division to supply calibrated detectors for particular radiometric purposes. The project structure is sufficiently fluid to allow for redirection of resources to accomplish newly identified program goals and has proven to be a useful management tool for tracking progress and assigning responsibility.

CURRENT DIRECTIONS

■ **High Accuracy Cryogenic Radiometry.** The Division has placed into service an absolute High Accuracy Cryogenic Radiometer (HACR) as the base for a radiometric measurement chain to maintain scales of spectral radiance and irradiance and scales of absolute detector responsivity. A second, high sensitivity cryogenic radiometer serves as the measurement basis for the Low Background Infrared (LBIR) calibration facility. This facility performs calibrations and serves as the foundation for research and development for technology applications in space and other areas where high sensitive infrared sensors are used.

The HACR instrument is used in conjunction with laser light sources to calibrate transfer standard detectors which can be used throughout the Division in radiometric application. The HACR has an intrinsic uncertainty of 0.01% or better and serves as the basis for improving and calibrating the NIST radiometric scales. The detector program is developing a series of transfer standard radiometers to enable the high accuracy radiometric scales maintained by these devices to be propagated to other laboratories. Recently the two cryogenic radiometers were intercompared using a silicon diode radiometer system and found to agree to better than 0.1%.

■ **Absolute Spectrophotometers.** Three absolute spectrophotometric instruments serve as the primary method for maintaining scales of transmittance, reflectance and optical density. They are: the reference transmittance spectrophotometer, the reference reflectance spectro-photometer, and the inverse fourth densitometer. These instruments operate in the 200-2500 nm wavelength range and provide calibrated samples as references for secondary instruments used for routine service calibrations. The intrinsic uncertainty of the transmittance and reflectance reference instruments is a part per ten thousand and a part per thousand respectively of the appropriate units. In addition to calibration services, SRM materials are prepared for distribution to industrial and scientific customers. New instruments for hemispherical reflectance and Bidirectional Scattering Distribution Function (BSDF) measurements are under development.

■ **Temperature.** The Division has the institutional responsibility for maintaining temperature scales above the freezing point of silver (1234.96 K) utilizing techniques of optical pyrometry. The pyrometry scale is based upon the spectral radiance scale and hence is inferred from the absolute detector scale based upon the HACR. A wide range of black body sources are maintained for calibration purposes. The Division pursues a vigorous program in thermal source research and development to provide the highest quality measurement assurance for our customers needing temperature scale calibration for a variety of industrial and scientific purposes. An effort is underway to place the radiation temperature scale upon an absolute detector base referred to the cryogenic radiometers.

■ **Photometry.** Photometry, the science of measuring light with the response function of an "average" human observer, is an activity that has been made integral to the detector characterization efforts in the Division. The unit of luminous intensity, the candela, is maintained on a set of well characterized, appropriately filtered, detectors. This provides a direct link between the HACR and the SI unit, the candela, and provides an alternate method of transferring this unit to calibration customers. Heretofore, the candela unit was disseminated by supplying calibrated lamps to customers for a fee. While this practice will be continued, depending upon lamp availability, we can offer photometric detector characterization to customers as a more direct and perhaps more stable calibration procedure. The Division staff have been active in joint efforts with CORM and the CCPR to identify and develop new sources of standard quality lamps for dissemination of these scales. Should these efforts bear the results anticipated, we should have new and agreed upon standard lamps for use in luminous intensity and luminous flux measurements.

■ **Radiometric Research.** The Division maintains research efforts in low level radiometry, biological applications, optical properties of cryogenically cooled materials, black body physics, and in new areas of spectrophotometry such as BSDF measurements.

■ **Consultation and Service.** The Division staff provides Standard Reference Materials and radiometric calibrations for use by a variety of industrial and academic customers. The staff has an active and vital role in consulting with other government agencies such as NASA, NOAA, and DoD to develop calibration programs appropriate for their demanding missions.

HIGHLIGHTS

■ **Bidirectional Scattering Metrology.** The Bidirectional Scattering Distribution Function (BSDF) of a surface describes the angular distribution of the radiance scattered by a surface normalized by the incident irradiance on the surface. Large discrepancies in BSDF measurements on both specular and diffuse surfaces exist among laboratories and contractors. These discrepancies pose difficulties in instrument procurement, evaluation of scattering properties, contract monitoring, and new materials development. The objective of this program is to develop state-of-the-art standard materials and the associated calibration procedures for BSDF measurements.

An expression describing bidirectional reflectance distribution function (BRDF) due to the scattering of gas molecules in the optical path was derived by J. Hsia based on the Rayleigh scattering theory and was compared to NIST measured data (Fig. 1). This work, performed by C. Asmail and J. Proctor, indicated the lowest level (BRDF) measurable was dependent on the index of refraction of the environment as predicted by the model. A factor of 10

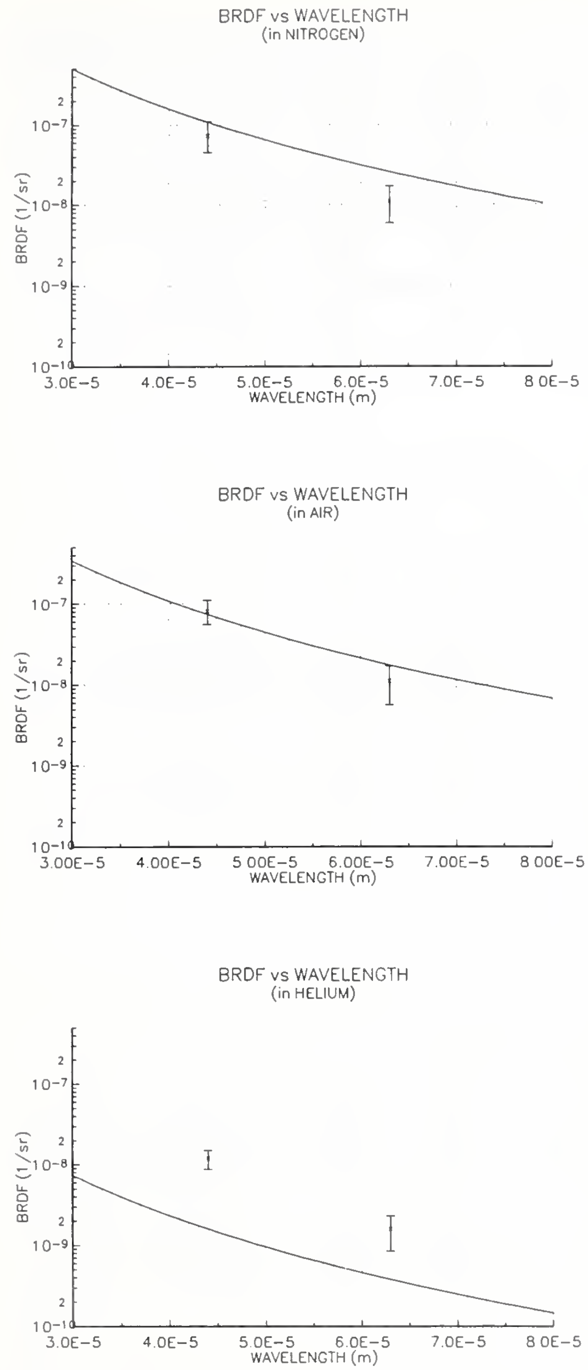


Figure 1 – Plot of theoretical BRDF as a function of wavelength with experimental data at 442 and 633 nm (top, nitrogen; middle, clean air; bottom, helium)

decrease in the low level limit was obtained by replacing a nitrogen environment with helium in the optical path region of the experiment.

For the visible 45/0 BRDF standard development, the measurements at 380, 450, 600, 700, and 770 nm of 21 samples from 11 laboratories were completed by Mrs. Yvonne Barnes. The standard deviation at each wavelength was about 0.6% of the measured BRDF value.

C. Asmail was responsible for the specular BRDF standard development. Three preliminary black-glass samples were prepared using different grinding and polishing techniques with resulting BRDF values of 10^{-2}, 10^{-4}, and 10^{-6} sr^{-1}. The reproducibility of these sample surfaces has not been determined.

The goniometer was fabricated, assembled, and aligned. The angular uncertainty of the detector arm was determined to be within the design goal of 0.01°. The mean equivalent BRDF due to instrument limitations, in the absence of a sample, is called the instrument signature. The instrument signature of the laser source system with two spatial filters was measured and shown to require reduction of stray light. A compact photomultiplier detector was evaluated and showed a NEP of 10^{-15} W which corresponds to 10^{-8} sr^{-1} BRDF with 5 mW incident power onto the sample surface and a receiver system with 2×10^{-5} sr solid angle. (C. Asmail and C. Cromer)

■ **Wavelength Standards for the Calibration of Infrared Spectrophotometers.** Spectrophotometers are instruments which are able to spectrally characterize the optical properties of materials. To obtain useful information from these instruments, both the photometric and wavelength (or frequency) scales must be calibrated. Standards are currently available which allow spectrophotometer users to perform such calibrations in the ultraviolet, visible and near infrared spectral regions. However, standards are not readily available for the mid-infrared (IR) spectral region (2 µm to 20 µm), in which large numbers of instruments are currently being utilized.

Polystyrene films have traditionally been employed for the calibration of the wavelength scale of infrared spectrophotometers. Wavelength values were generally obtained from published papers. However, in the 1970's, with the advent of laser based monitoring and fast computers, fourier transform infrared (FTIR) spectrophotometers became commercially available. These instruments are generally operated in higher resolution than dispersive spectrophotometers. Polystyrene films are available in many forms, with varying finish and thickness. These different films have absorption peaks which vary somewhat in wavelength from film type to film type. Although the wavelength differences are negligible at low resolution, the differences are too large to use nominal literature values for high resolution FTIR wavelength calibration. Hence a need has developed to establish the wavelength scale consistent with the requirements of high resolution instruments.

Recently, the Radiometric Physics Division has developed a polystyrene standard reference material (SRM) for calibration of the wavelength scale of spectrophotometers operating in the mid-IR. The SRM provides seven primary reference wavelengths, each with a total uncertainty of less than 0.5 cm^{-1} for the calibration of FTIR instruments. In addition, six more secondary wavelengths, each with a total uncertainty of ≈ 1 cm^{-1}, are provided. A typical transmission spectrum of the polystyrene SRM is shown in Fig. 2. The absorption lines used for the primary

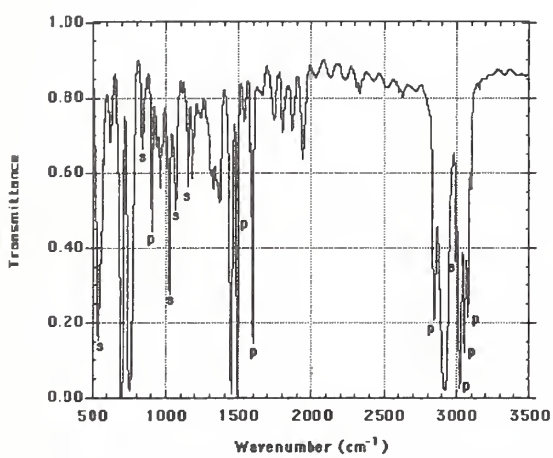


Figure 2 – Infrared transmittance spectrum of polystyrene film SRM from 500 cm^{-1} to 3500 cm^{-1} (2.9 μm to 20 μm). Absorption lines to be used for wavelength calibration are labeled 'p' (primary) and 's' (secondary).

and secondary level wavelengths are indicated by 'p' and 's,' respectively. The approximate wavenumber values are listed below in table 1. (J. Hsia and K. Eckerle)

Table 1

Primary (cm^{-1})	Secondary (cm^{-1})
906	544
1583	842
1601	1028
2849	1068
3026	1154
3060	3001
3082	

Ambient Background IR Detector Characterization Facility. Presently NIST has the capability to perform detector responsivity calibrations in the 200 nm to 1.8 μm spectral range. To meet the needs of the IR user community, the Radiometric Physics Division at NIST is working to extend this spectral coverage to 25 μm. An ambient background facility employing a prism/grating monochromator is currently under construction. A high sensitivity, spectrally flat, cryogenic bolometer is being tested for use as a transfer standard. The responsivity of this bolometer will be tied to the High Accuracy Cryogenic Radiometer. This will allow the responsivity of IR detectors to be traced to the national primary standard.

The cryogenic bolometer consists of an absorber attached to a thermal sensor. Incident radiant energy heats the absorber and is detected as a temperature rise. This bolometer was designed to have low heat capacity and low noise allowing for large detector area, high frequency response, and high sensitivity. The absorber is a 5 mm diameter by 0.05 mm thick sapphire disk with its surface coated with gold black for high absorption and spectral flatness. A doped-Si chip is bonded to the back of the sapphire disk. Temperature changes are seen as resistance changes of the Si chip. The electrical leads of the Si chip also provide the thermal link between the bolometer and the reference cold plate.

The electrical and radiometric properties of the bolometer have been measured. The sensitivity was found to be 20 pW, instability less than 1%, responsivity 1.7×10^6 V/W, and spatial nonuniformity less than 1%. The nonlinearity was less than 1% over 5 decades with the range limited by the detector (Fig. 3). These results are

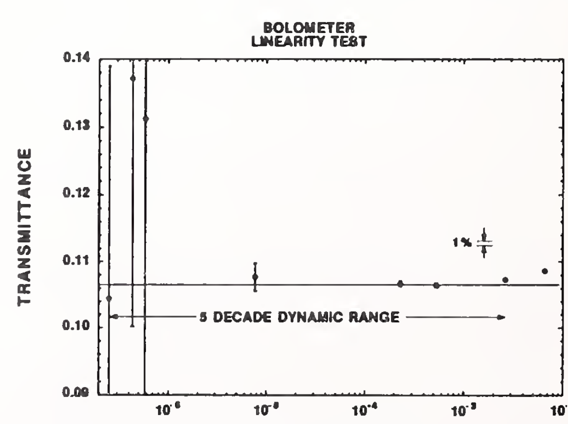


Figure 3 – Bolometer linearity test

IR DETECTOR SPECTRAL CALIBRATION FACILITY

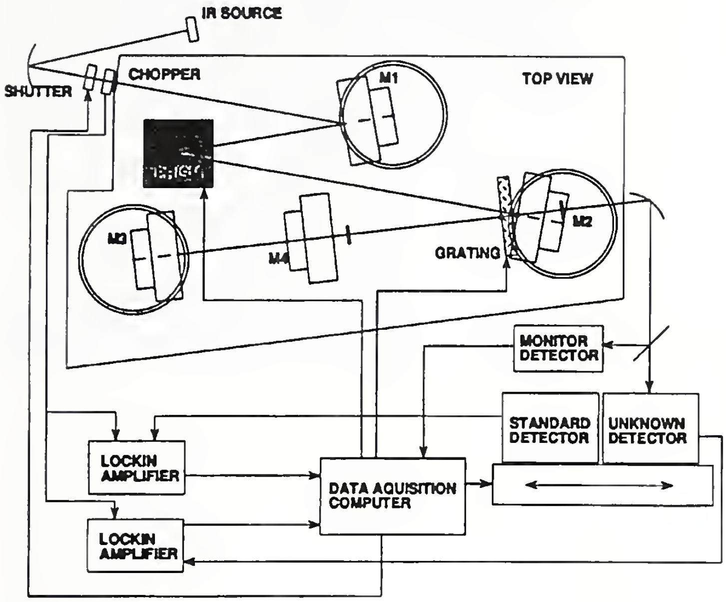


Figure 4 – Schematic of the prism-grating monochromator for IR detector calibrations.

being used to make a number of improvements. An independent temperature sensor will be installed on the cold plate to monitor the stability. The properties that are planned to be studied are spectral reflectance of the gold black coating at cryogenic temperatures and absolute responsivity. This bolometer shows promise to be used as a transfer standard.

The monochromator construction and testing is nearly complete. The optical schematic is shown in Fig. 4. We have set up a computer system to control an optical chopper, lock-in amplifier, shutter, digital multimeters and the monochromator, and to record measurements using the bolometer. These tests allowed us to optimize the instrumentation accuracy. We found that the non-linearity of the entire system is about 2% over 3 decades and is limited by the bolometer itself. The spatial uniformity and stability are also under investigation. We are currently considering the best way to improve these characteristics. Spectral scans using several different types of detectors, including the cryogenic bolometer, have been made using a ceramic IR source and the monochromator.

Also, a new IR source with 2 to 8 times the brightness of conventional sources is being studied as a working source for the monochromator. The spectral measurement of this source, an argon discharge, will be made using monochromator and bolometer. Optimum operating parameters and the ultimate usefulness of this source will be determined. (A. Migdall and R. Datla)

■ **High T_c Superconductors for Radiometry; Cooperative Research Program with the University of Maryland.** A cooperative research program with the University of Maryland to investigate optical and thermal properties of high T_c superconductors to build absolute radiometers at liquid nitrogen temperatures has been established. So far cryogenic absolute radiometers have been constructed that operate at liquid helium temperatures. It is intended to use thermal modelling to optimize the parameters for the design. Z. Zhang and D. Drew of the University of Maryland at College Park have been working with NIST researchers on this project.

Absolute cryogenic radiometers having a flat response in the visible to far infrared region of the spectrum have become the absolute standard detectors for radiometric calibrations at NIST, and similar radiometers have been playing an important role in the measurements of solar constant and solar irradiance, earth radiation budget, laser power calibrations etc. The Low Background Infrared (LBIR) calibration facility at NIST is employing a germanium resistance thermometer (GRT) based radiometer at liquid helium temperatures to measure power levels of 20 nW to 100 μW. A more sensitive radiometer using a superconducting kinetic-inductance thermometer as the temperature sensor (SKACR) has been constructed for measuring sub-nanowatt power levels.

The receiving cones for these radiometers have been constructed based on the experience of the designer and empirical optimization. Z. Zhang undertook thermal modelling of the receivers of these radiometers to compare the predicted and observed performance and to extend the modelling for the design and construction of the high T_c film based radiometer. A finite-element technique is employed to predict the transient and steady-state temperature distribution in the receiver cones. Some important conclusions of this study are the following.

1. The nonequivalence due to the nonuniform temperature distribution in the receiver is 0.02% in the GRT based ACR (Fig. 5) in agree-

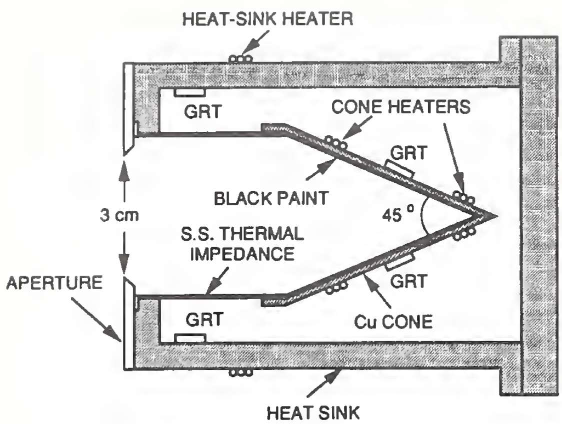


Figure 5 – Schematic of GRT-based Absolute Cryogenic Radiometer (ACR)

ment with the experimental value. However, it was shown this can be reduced by locating the temperature sensor close to the thermal impedance. The nonequivalence of the SKACR (the symmetric top half shown in Fig. 6) is less than 0.003 percent.

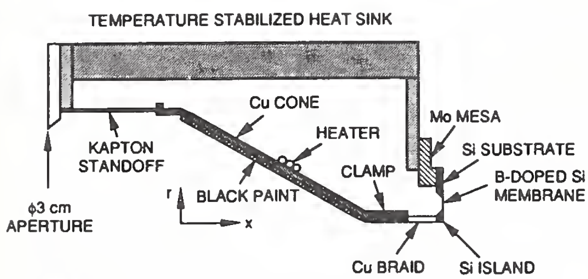


Figure 6 – Schematic of the top half of the superconducting kinetic-inductance absolute cryogenic radiometer (SKACR).

2. The ultimate sensitivity of the cryogenic radiometers is limited by the random noise.

3. The time constant of the GRT based radiometer can be reduced by modifying the material or geometry of the thermal impedance in the present design. The dynamic response of the SKACR can be improved by reducing the thickness of the black paint (Fig. 7).

Besides the use of high-T_c films for transition temperature based radiometers, a promising application is to construct highly sensitive infrared detectors. These detectors will operate near 77 K and have greater sensitivity than any of the existing detectors operating at or above 77 K for radiation wavelengths longer than 20 µm. One of the principal objectives of the current research project is to optimize combinations of high-T_c superconductors and substrates for radiometric applications. The study will employ an FTIR spectrometer at NIST to investigate the optical properties of a variety of high-T_c superconducting films and substrates for wavelengths between 1 and 1000 µm at cryogenic temperatures. In addition to the superconductor $YBa_2Cu_3O_7$ ($T_c \approx 90$ K), superconducting thin films of $Bi_2Sr_2CaCu_2O_8$ ($T_c \approx 85$ K), $Bi_2Sr_2Ca_2Cu_3O_{10}$ ($T_c \approx 110$ K), $Tl_2Ba_2CaCu_2O_8$ ($T_c \approx 100$ K), $Tl_2Ba_2Ca_2Cu_3O_{10}$ ($T_c \approx 125$ K) will be investigated. Potential substrates for this study are $LaAlO_3$, $LaGaO_3$, $NdGaO_3$, $NdAlO_3$, $SrTiO_3$, MgO, sapphire, ZrO_2, and Si with Y-stabilized ZrO_2. (R. Datla and A. Frenkel)

■ Operation and Expansion of the LBIR Facility. The Low Background Infrared (LBIR) facility had been very active with the low background test measurements of blackbodies for the aerospace contractors of DoD. The NIST LBIR User Board, in their meeting held at Arnold AFB, on May 12, 1992, expressed the need to equip the LBIR facility with spectral capability. The Midcourse Space Experiment (MSX) program office of SDIO gave extra funds to acquire the capability and expand the facility. The task of operating the current facility for the measurements of customer blackbodies and initiating the expansion of the facility for spectral capability has been successfully handled by the staff of the IR radiometry group.

As part of LBIR expansion to provide spectral calibrations, a cryogenic blackbody was constructed and tested. The blackbody is equipped with 6 apertures from 250 µm to 2 mm in diameter and a filter wheel that will accommodate 8 filters (Fig. 8). This NIST cryogenic blackbody will be a general purpose source for many activities, including detector calibrations, optical materials characterization, and periodic evaluation of ACR performance. Also, a spectrally tunable IR source was constructed and evalu-

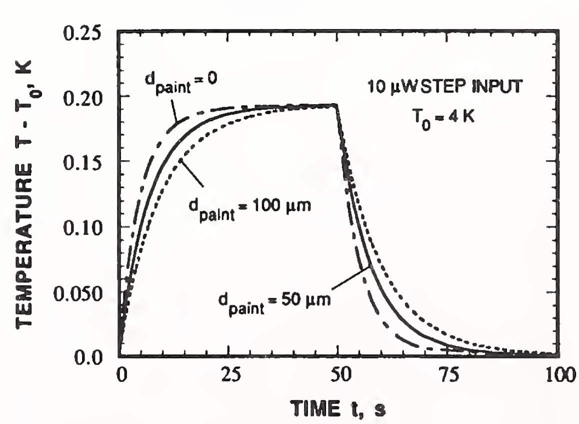


Figure 7 – Dynamic response of SKACR for various thicknesses of the black paint.

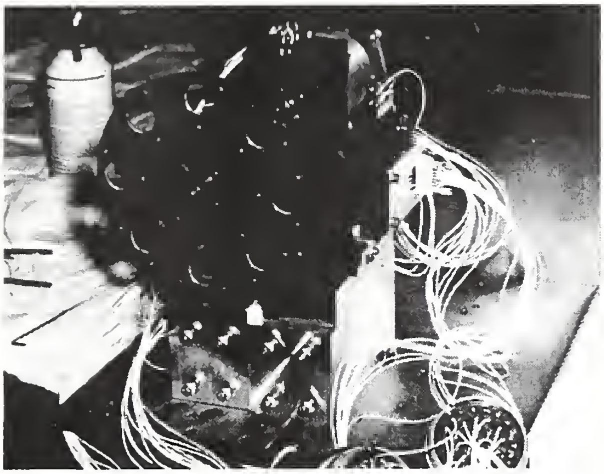


Figure 8 – LBIR facility's blackbody

ated. It incorporates lead salt lasers with wavelengths of 5 μm, 10 μm and 20 μm mounted inside an integrating sphere to remove spatial coherence. This source operates at 20 K inside the LBIR chamber and will be useful for evaluation of a variety of spectral instrument characteristics. The fabrication of the prism grating spectrometer for the LBIR facility was completed by the Talandic Corporation of Irwindale, CA. The instrument will be installed in the LBIR chamber after it is assembled and tested by the contractor. (S. Ebner and S. Lorentz)

■ **High Accuracy Cryogenic Radiometer.** The absolute uncertainty of the HACR for optical power measurements is 0.01% or better. A measurement cycle consists of alternate measurements of the asymptotic temperature of the receiver cavity with optical and electrical heating. Since the thermal time constant of the radiometer cavity is 4 minutes, the time required to reach 99.99% of the asymptotic temperature is roughly 10 time constants or 40 minutes. A single measurement requiring one optical and two electrical heating cycles can take more than 2 hours, which can result in reduced accuracy due to drift in the system. To improve this situation, and increase the throughput of measurements made with the HACR, we have automated the measurement process which includes a new method for predicting the asymptotic temperature of the cavity. This decreases the time for one measurement to less than 45 minutes, significantly increasing the throughput and accuracy of measurements made with the HACR.

We have completed the first series of measurements with the HACR using trap detectors developed for use as high accuracy transfer detectors. We have submitted for publication the results shown in Fig. 9 comparing the previous

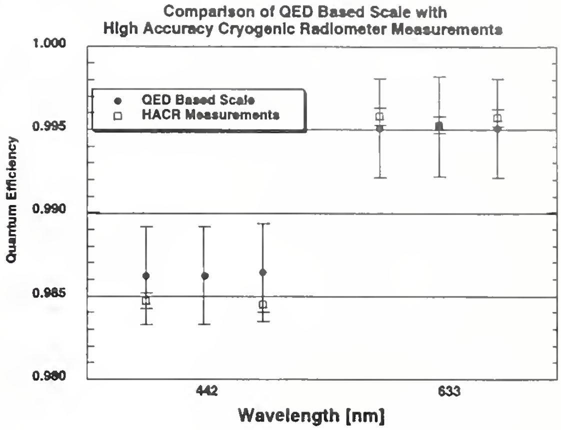


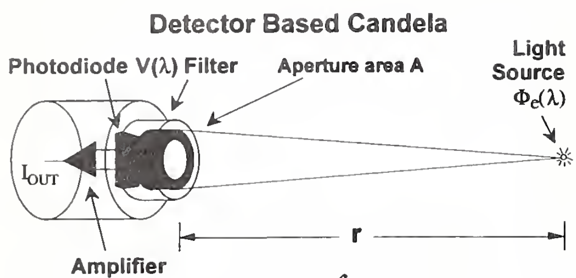
Figure 9

detector spectral response scale with the HACR, showing better than 0.1% agreement at 633 nm.

Trap detectors constructed with silicon photodiodes are used as high accuracy transfer detectors. These trap detectors can be calibrated with the HACR at fixed laser wavelengths. The trap detectors can then be used to calibrate working standards. We have developed an improved trap detector which has six photodiodes arranged to transmit radiation through the device. This eliminates any residual reflectance, and provides for easier alignment. This new trap detector will be used for future spectral response scale realizations, a state of the art measurement of a high temperature blackbody, and a new high accuracy candela realization.

We have also begun construction of a laser comparator facility to complement the capabilities of the HACR. It will be used to provide high accuracy transfer from calibrated trap detectors to other transfer standards using intensity stabilized lasers. (J. Houston, C. Cromer, and J. Hardis)

■ **Photometry.** The Radiometric Physics Division at NIST is responsible for the realization of the SI base unit, the candela. The candela represents a unit of measure of the apparent brightness of a light source as observed by the human eye. Traditionally the candela was realized using blackbodies operated at the freezing point of various pure metals. NIST has realized the candela using standard detectors which were constructed to emulate the CIE spectral lumi-



$$I_V\,[\mathrm{cd}] = K_m\, I_{OUT}\, \frac{r^2}{A}\, \frac{\int_\lambda \Phi_e(\lambda)\, V(\lambda)\, d\lambda}{\int_\lambda \Phi_e(\lambda)\, s(\lambda)\, d\lambda}$$

Figure 10

nous efficiency function for photopic vision (Fig. 10). A group of eight photometers are constructed using glass filters and silicon photodiodes. The photometers are calibrated for absolute spectral response using working standards that are traceable to the NIST high accuracy cryogenic radiometer (HACR). The photometers are used with an automatic measurement bench to determine the luminous intensity (candela) for a standard lamp. The uncertainty in determining the candela value is 0.4% (2σ), an improvement of more than a factor of two over traditional methods. We have also recently built a group of colorimeters which, when used with the standard photometers, allow accurate measurement of the tricolor stimulus values of a source.

The photometry project is headed by a new employee, Y. Ohno, who has joined us from Matsushita Corporation of Japan. He has developed a technique for the absolute measurement of luminous and spectral flux using an integrating sphere. This method is significantly less expensive and potentially more accurate that traditional methods using goniometers. We will be applying this new method for luminous and spectral flux calibration services. We also have plans to use the new "tunnel" trap detectors developed for use with the HACR to further improve the accuracy of the realization of the candela. Uncertainties of 0.1% or better should be achievable. (Y. Ohno and C. Cromer)

■ **Remote Sensing.** The goal of *NASA's Earth Observing System (EOS)* science mission is to advance the understanding of the entire Earth system on the global scale by developing a deeper comprehension of the components of that system, the interaction among them, and how the Earth system is changing. To quantify changes in the Earth system EOS will provide a systematic, continuing observation from low Earth orbit for a minimum of 15 years. The Radiometric Physics Division has been advising NASA on the calibration problems of several of the instrument packages such as MODIS, ASTER, and MOPITT.

ASTER is being sponsored by the National Measurement Laboratory (NML) of Japan and will be on the EOS platform. NIST will participate with NML by intercomparing NIST and NML blackbodies. This task is a subset of the intercomparison of all the instruments on the platform. A program has been developed and will be carried out in 1993. It will involve intercomparing blackbodies both at NML and NIST.

GOES is part of the NOAA weather network. Our task was to investigate the radiometric calibration procedures of the GOES program and to evaluate the calibration capabilities of the prime vendors. Out of this evaluation NIST was to suggest recommendations for an improved calibration program for the infrared sensor system on the GOES platform. NIST staff visited the three main contractors (LIRIS, EG&G Judson and ITT) associated with developing the instruments for the infrared radiometric measurements.

Recommendations were submitted to NASA and NOAA. As with most instruments of this type, no thought had been given to the radiometric calibration. Therefore, the prime recommendation was that the calibration process must be studied from the fundamental optical physics viewpoint, the sources of error identified, and their effects on the final measurement determined. A comprehensive approach to this problem involves writing a measurement equation that incorporates all the relevant parameters and their relationships. (B.C. Johnson and R. Saunders)

■ **SEAWIFS.** SeaWiFS is a NASA/NOAA project to study ocean color to provide estimates of chlorophyll concentration and other bio-optical observations of the upper ocean layers. The satellite instrument will measure upwelling radiances at eight spectral bands in the visible and near-infrared region from 412 nm to 865 nm. The project includes a large number of ground truth measurements with a variety of radiometers and spectroradiometers deployed in the ocean. Simultaneous measurements made by the satellite and the field instruments provide a verification of the validity of the satellite data products. NIST is assisting the project by providing calibrated standards and by sponsoring round robin intercomparisons among the various participant laboratories. NIST personnel participated in one intercomparison held at San Diego State University in July 1992, and a second intercomparison is planned for June 1993. The second intercomparison will be approximately four months before the launch of the SeaWiFS satellite. NIST is also developing a portable multichannel radiometer for calibration source verification and validation at the calibration laboratory sites and on board ships during deployment of the field instrumentation. (B.C. Johnson and R. Saunders)

■ **Argus.** The SDIO has been funding a variety of remote sensing laboratories to provide data on emission of radiation from rocket plumes. One element of this program is called Argus and is being implemented by Phillips Laboratories at Kirtland AFB in Albuquerque, NM. The Argus program consists of a variety of instruments which cover the spectral range from the ultraviolet to the far infrared using spectroradiometers and multispectral imaging cameras. These instruments are installed in an aircraft and are used to observe rocket launches. NIST is being funded by SDIO to participate in calibration planning and to assist in improving the accuracy of data products from the program. This is accomplished by making recommendations for improved calibration methodologies, and by supplying standards as appropriate. (B.C. Johnson and C. Cromer)

■ **A Method of Realizing Spectral Irradiance Based on an Absolute Cryogenic Radiometer.** A technique was developed for realizing spectral irradiance using a large-area, high temperature, uniform, blackbody source and filter-radiometers that are calibrated using a high-accuracy cryogenic radiometer. This project was funded in part by Director's reserve funding, and is in response to requests by American industry for improved spectral irradiance and radiance standards.

The ultimate goal of the program is to reduce the measurement uncertainties in the spectral irradiance scales that are made available to industry by calibrating deuterium and tungsten-halogen irradiance lamps. In order to do this, fundamental changes to the methods used to realize the spectral irradiance scales are required. In effect, the method that we are studying comprises two major changes. First, the number of steps required for realizing the scale from the primary standard (the High Accuracy Cryogenic Radiometer) to the source standard (the irradiance lamps) will be reduced by using the high temperature blackbody source as the irradiance standard. Second, the temperature scale of this blackbody source will be realized in terms of the filter-radiometers. The key components required for implementing the research program are procured or are in construction, and experimental measurements will commence shortly. The method will be studied by calibrating irradiance lamps using this new technique and comparing with the results obtained using the method currently employed at NIST. Independent measurements of the temperature of the blackbody source will also be made as part of this study.

In 1992, the initial measurement setup was completed (Fig. 11). A high-temperature blackbody was developed and tested for radiance and irradiance stability and uniformity. The major problem was developing software to stabilize the output of the blackbody to less than 0.05%. This stability was needed to meet the goal of the project, a spectral irradiance scale with an uncertainty close to a few tenths of a percent. The second effort of this project was to develop an radiometer that can be calibrated using the NIST High Accuracy Radiometer (HACR). A new

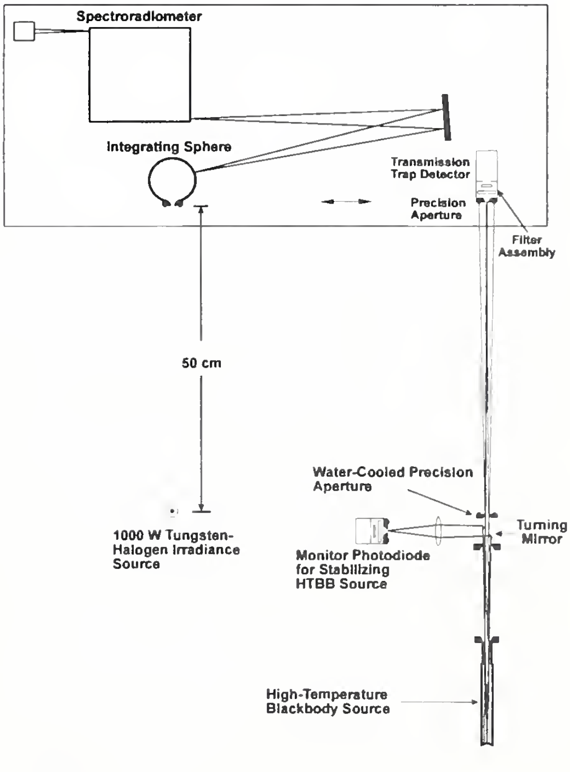


Figure 11 – Calibration set-up.

type of trap detector was developed by C. Cromer and is discussed elsewhere. The important feature of this trap is that there is no return beam to inter-reflect with the bandpass filter of the radiometer. This return beam has been a major problem in achieving the highest accuracy with radiometers using interference filters. In this project, six different detectors were developed to cover the spectral region 350-900 nm. (R. Saunders, V. Sapritsky, and B.C. Johnson)

■ **Solar Radiometry.** The proposed global environmental problems of stratospheric ozone depletion and the greenhouse effect are intimately involved with changes in the transmission of the atmosphere resulting in changes in the spectral irradiance of solar radiation reaching the earth. Stratospheric ozone depletion is projected to cause a substantial increase in transmitted ultraviolet (UV) radiation. This may have serious health and safety consequences as well as significant deleterious effects in agriculture, materials, and exposed finishes. The determination of whether these solar spectral irradiances are actually changing require extremely accurate long term measurements.

The NIST Radiometric Physics Division is currently building the instrumentation and formulating the procedures necessary to characterize the solar UV instrumentation being deployed in the United States Department of Agriculture (USDA) networks. Instruments have been selected by the instrument advisory panel for evaluation and subsequent deployment in a status-and-trends network. The instrument laboratory characterizations will in general comprise: linearity, stray light rejection, cosine response, wavelength and irradiance calibration, and, where applicable, slit function measurements and responsivity. For most of the broadband and filter wheel instruments the final calibrations and uncertainty measurements will be carried out with the sun as a source and with a high accuracy spectroradiometer. A science panel representing instrument experts will be responsible for selecting the candidate instruments and evaluating characterization results prior to network deployment. NIST, with USDA support, will also operate a UV-B spectroradiometer intercomparison at the first USDA network/DoE ARM site in the fall of 1993. It is expected that reference instruments will be present at the intercomparison from the NSF Antarctica program, the EPA and other international UV-B networks.

The EPA has indicated an interest in continuing this relationship. The Radiometric Physics Division is also involved with NASA/NOAA climatic change satellite projects such as GOES, EOS, SBUV, and SSBUV and has submitted a proposal to evaluate the new TOMS instrument before its launch.

The Radiometric Physics Division is committed to assisting the agencies involved in the Global Climatic Change Initiative and believes the mission to be of pressing national and international interest. (A. Thompson and J. Walker)

■ **Pyrometry.** NIST has enlarged its efforts in the radiance temperature field by developing blackbody standards from 0 °C to 3200 °C. This increased effort included the characterization of a cesium heat-pipe blackbody, a sodium heat-pipe blackbody, and the development of a low temperature (0 °C to 500 °C) graphite blackbody. These blackbodies have extended the NIST Radiance Temperature Scale from 0 °C to 3200 °C. This work will be completed in 1993, giving NIST a radiance temperature measurement capability that will meet most of the major needs for developing technologies. These blackbodies will be the basis for our work in imaging radiometry.

Investigations into using a Fourier spectrometer for radiometric purposes was initiated. Fourier spectroradiometers have been used for years in spectroscopy but little effort has been devoted to using this type of instrument in radiometry. These instruments usually have good spectral accuracy and resolution but poor intensity stability. For spectroscopy, radiance repeatability and stability is sacrificed for high resolution (<0.001 nm). Since high resolution is not needed for the intended radiometric applications, lower resolution (0.1 nm) may allow improved radiometric stability. A low resolution Fourier instrument was purchased for this task. The optics to view blackbodies, lamps, and argon min-arcs has been designed and the optical components are being ordered. If this radiometer works according to expectations, it will give the Thermal Radiometry Group a valuable tool in studying the emissivity of blackbodies and the output of argon mini-arc IR sources. The measurement of the infrared output of an argon mini-arc is a collaborative effort with the Atomic Physic Division and is being sponsored by SDIO. The mini-arc is being studied for use as an infrared source in the spectral region 2 to 5 μm. The radiance output of the argon mini-arc in the infrared has never been measured but theory says that it should be several orders of magnitude higher than conventional thermal sources. (C. Gibson and R. Saunders)

■ **Calibrations.** A calibrated photometric detector was used to monitor the output of spectral irradiance lamps and standards measured on FASCAL. This photometric radiometer was of the same design used for the photometric detector packages used to maintain the NIST photometric scale. Although this radiometric package was installed on FASCAL last year, this was the first year that it was used for all spectral irradiance measurements including scale realizations. This detector is providing a link between the NIST detector scale based on the HACR and the NIST spectral irradiance scale. The results of this improvement are encouraging. In addition to giving up-to-the-minute stability data on the spectral irradiance lamps used to maintain the NIST spectral irradiance scale, the data show that the NIST detector scale and the NIST spectral irradiance scale are in agreement in the spectral region 400-800 nm to better then 0.5%.

A detector package for the UV spectral region (250-350 nm) was developed and installed on the solar monitoring package used for the space community. The detector was used at NIST and sent out with the package but has not been returned yet. For this reason, the results from the first round have not been completely analyzed. The long term stability was not checked because of time constraints but will be the limiting feature of the detector package. Developing a stable detector in the region is difficult because of the high energy of the photon which degrades filters and detectors. Other UV detector packages are being developed by the Detector Metrology Group that will have a smaller bandpass and can be used on FASCAL to link the UV spectral region to the NIST detector scale. This work will be completed in 1993. (J. Jackson and R. Saunders)

■ **AIR-UV Intercomparison (200 - 400 nm).** The CCPR is conducting an intercomparison among four National laboratories. The participating laboratories are NIST (USA), PTB (Germany, Braunschweig and Berlin), VNIIOFI (Russia), and NPL (England), with PTB Berlin being the coordinating laboratory. The intercomparison will involve both a tungsten lamp and nine deuterium lamps. NIST is supplying three uncalibrated Hamamatsu deuterium lamps, NPL is supplying three Cathodeon deuterium lamps, and PTB is supplying three Heraeus deuterium lamps for this intercomparison. The mounts for the lamps were designed by PTB and are different than the standard NIST lamp mount design. The intercomparison will be conducted as a circular intercomparison, with NPL being the central laboratory making the initial and final measurements. NIST will measure the lamps in July of 1993 for both spectral radiance and spectral irradiance. The intercomparison is expected to be completed by December 1993. The driving force behind this intercomparison is the need to improve the accuracy of radiometric measurement below 400 nm for a variety of health and environmental as well as scientific reasons. The Radiometric Physics Division is now addressing these areas with its detector program and the development of a spectral irradiance scale based on the HACR. (R. Saunders and C. Cromer)

FUTURE OPPORTUNITIES & DIRECTIONS

■ **Need for Improved Radiometry.** Environmental and health concerns about the penetration of UV radiation into the biosphere due to ozone depletion has renewed emphasis on the necessity for accurate and reliable uv radiometry. The role of "greenhouse" gases in determining the global radiation balance is studied in part by careful monitoring of solar radiation from space and on earth. NIST is in a unique position within the government to offer long term measurement support for USDA, NASA, and other agencies. Requirements for defining health effects and determining energy efficiency of building and outdoor lighting also drive the need for improved radiometry in the uv and visible.

■ **Infrared Characterization Facilities.** The growing interest in space-based observations for both civilian and defense purposes and emerging industrial applications demands development of infrared spectral radiometric calibration and characterization facilities. This includes the development of detector characterization facilities for both low-background and ambient-background applications, as well as the development of appropriate sources and source characterization facilities for customers whose measurement needs can best be met by high quality radiometric sources.

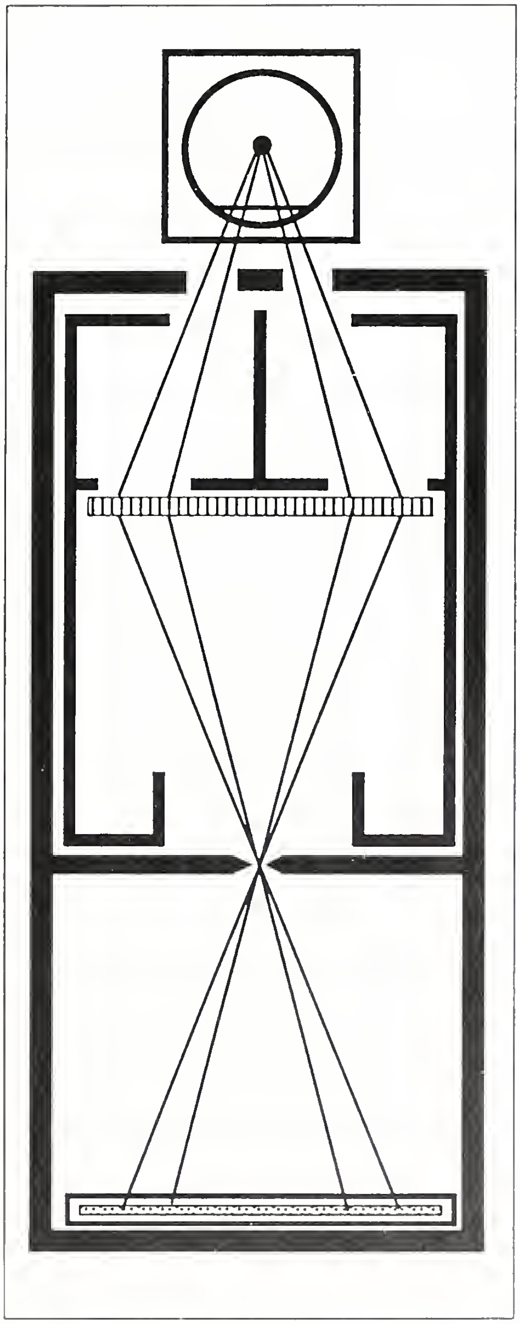
■ **Optical Properties of Materials.** Optical properties of materials measured under a variety of temperature conditions, and to much better precision, are required for a number of scientific and technical applications. Space-based systems have new demanding requirements for spectral emittance and transmittance. Details of the scattering of light from optical surfaces are important for characterizing a number of sophisticated optical systems, requiring the development of new measurement techniques. The rapidly evolving photonics industry has generated new requirements for accurate information on materials used in a variety of devices which underpin new technologies. NIST must help meet these challenges by developing technical expertise and furnishing calibration and measurement support.

■ **Improved Radiometric Standards.** American industry has expressed the need for improved radiometric standards for a variety of technical, competitive, and production quality reasons. These needs have been documented in the CORM 5th report, and projects designed to answer some of the issues have served as an impetus for several Director's reserve proposals. The challenge remains to implement the necessary methodology and instrumentation to meet the needs of our customers.

■ **Increased Range of Absolute Detectors.** Over the last several decades, absolute detectors have been developed to serve as the fundamental radiometric base. A challenge is to develop this capability for all wavelengths of interest and at the various power levels needed by the calibration customers. In terms of optical power, the demands can be over 12 decades of intensity and with many varied detectors and background circumstances. In many calibration activities, detector-based radiometry can replace traditional source-based techniques for improved accuracy. It will be a challenge for the Division to provide the technical base for this conversion where appropriate, and to provide the leadership and guidance to achieve the desired results.

■ **Imaging Radiometry.** Electronic rendition and storage of images offer exciting new opportunities for radiometric characterization of light sources and for temperature determination of spatially resolved objects. This field is undergoing a fundamental change, from the silver chemistry of conventional image storage and recording, to electronic and magnetic media. To accommodate this revolutionary change, radiometric procedures will be developed to characterize and standardize the measuring processes and to provide a national basis for image analysis related to the spectroradiometric output of objects. □

QUANTUM METROLOGY DIVISION



Overleaf

Wavelength Dispersive X-Ray Spectrograph. The cover illustration is a diagram of a simple wavelength dispersive spectrograph whose geometry is adapted from the 1914 work of Rutherford and Andrade. We find that it is an appropriate tool for non-invasive measurement of the high potential (the so-called kV_p) applied to x-ray tubes used in diagnostic radiology, especially mammography where sub-kV changes are found to perturb image quality (see Highlights).

QUANTUM METROLOGY DIVISION

MISSION

The Quantum Metrology Division engages in a program of fundamental and applied research characterized by strong coupling between advances in measurement technology and basic physics. In particular, the Division

- addresses problems in the determination of fundamental physical constants and interacts with others in the Physics Laboratory and other Laboratories in NIST where work in fundamental quantities occurs;
- contributes to the extension and refinement of the electromagnetic scale and devises tests of basic symmetries and invariances;
- maintains continuing efforts in several discipline areas including fundamental x-ray spectroscopy of atoms, molecules and simple solids, spectra of laboratory and astrophysical plasmas, and application of high accuracy measurements to the study of calculable spectra of basic scientific interest;
- advances x-ray technology in support of space research, industrial applications and medical radiology.

ORGANIZATION

The Division employs eight full time permanent scientists (including the Division Chief) and one secretary. Because of its small size, there are no groups within the Division. There is considerable flexibility in the permanent staff concerning their ability and willingness to contribute to the various projects within the Division. Roughly, two people are assigned to studies with synchrotron radiation, three and one-half people to precision measurements with x-rays and gamma-rays, one and one-half people to external collaborations, and one person to theoretical studies. Two other full time individuals are supported with Division resources: a technician at the NSLS and a machinist from the Fabrication Technology Division.

In addition, there are typically three to five long-term guest researchers from academia and international laboratories and one to two individuals on contract. In the past year guest researchers from Oxford University, Gesselschaft für Schwerionenforschung (GSI), SERC Daresbury Laboratory, Université Pierre et Marie Curie, Kurchatov Atomic Energy Institute, Moscow, and Argonne National Laboratory have participated in the Division's programs. The three individuals on contract during the past year have contributed to research on x-ray multilayer structures and analysis of x-ray data taken at the NSLS.

CURRENT DIRECTIONS

In its origin and initial directions, the Division was intended to address physical problems where enhanced measurement technology appeared critical. It was focused on fundamental constants and the evolution of certain units of measurement toward an atomic basis. The initial efforts were directed toward introduction of laser wavelength standards, linking infrared and visible lasers, mass, density and isotopic abundance (leading to the Avogadro constant), gravitational measurements (G), and unification of the electromagnetic scale to the gamma-ray region. Ongoing inner-shell physics and x-ray technology efforts currently benefit from special funding (a competence program and Director's reserve funding) and by external support from NASA for calibration of flight hardware directed toward high energy astrophysics, and from DARPA for multi-layer optic characterization.

■ **Precision X-Ray and Gamma-Ray Measurements.** This work has significant impact on the determination of fundamental physical constants, the masses of elementary particles and precise tests of physical theory. The secondary standards ladder begins with an iodine stabilized HeNe laser (closely coupled to the current definition of length and, more significantly, the basis for all modern determinations of the Rydberg constant). This laser is applied to the measurement of the lattice period of a highly perfect sample of monocrystalline Si near 0.2 nm in a procedure combining x-ray and optical interferometry (the XROI experiment). Transfer of this datum to other crystal samples, including different crystal species, takes place in a precision lattice comparator (the delta-d apparatus) designed to give precise lattice parameter differences with only small sensitivity to the unfavorable aspects of x-ray line profiles. Finally, these calibrated crystals are used in several absolute angle measuring engines to determine the wavelengths of x-ray and gamma-ray secondary standards. These diffraction spectrometers include a vacuum spectrometer for low energy x-ray measurements and two small angle transmission spectrometers, one for high energy x-ray measurements in the Radiation Physics Building and one for gamma-ray measurements at the Institut Laue Langevin (ILL), Grenoble, France. Significant developments have transpired in all three phases of this exercise over the past year.

In addition to determination of spectroscopic standards, this program applies such standards to the measurement of calculable spectra of normal and exotic atoms both to establish values for the masses of certain elementary particles, and in other experimental venues where the objective is to provide critical tests of basic physical theory. The rather formidable measurement technology developed in this program has enjoyed a considerable range of application outside the originally intended scope as will be detailed in the following paragraphs.

The absolute angle measuring spectrometer for gamma-ray wavelengths located at the ILL permits crystals and materials to be characterized at energies which are more than an order of magnitude higher (a few hundred keV to 2 MeV) than energies normally used (5 to 60 keV). Two examples of such measurements include crystal structure factor determinations and measurements of indices of refraction. In the case of structure factors, scattering processes such as Delbruck scattering and pair production which increase with increasing energy should be observable, given sufficient measurement precision. Index of refraction measurements yield values for the real part of the atomic scattering factor. At low energies anomalous contributions to the scattering factor are large and thus the detection of small additional terms predicted by theoretical calculations is difficult. At higher energies the anomalous contributions are significantly reduced making the interesting small additional terms more easily detectable.

Another application of the precision gamma-ray measurement technology has been the determination of nuclear lifetimes and of (the not so obviously related) inter-atomic potentials in solids (see Highlights). Again, the combination of intense gamma-ray beams and the high resolution crystal spectrometer permit the measurement of Doppler broadening induced by gamma-ray emission. Following neutron capture, the nucleus decays by emission of a gamma-ray (primary) which causes the nucleus to recoil. A secondary gamma-ray emitted by the recoiling nucleus is Doppler broadened with the broadening being dependent upon the initial recoil velocity, the slowing down process, and the decay time of the secondary level. Nuclear lifetimes in the 10^{-12} to 10^{-16} sec range have been measured and parameters characterizing inter-atomic potentials determined.

■ **X-Ray Inner-Shell Physics (Synchrotron Radiation Studies).** The long-term effort in x-ray inner-shell physics aims to elucidate the mechanisms underlying the finer details of x-ray processes in atoms, molecules and simple solids. These mechanisms are of two-fold interest in that they reveal dynamic processes on a uniquely restricted scale of small distances and small times while, at the same time, they confound efforts to derive information about atomic and electronic arrangements based on simplified models of inner-shell processes. The objective of this program is to exploit the well-known sensitivity of x-ray spectral detail to atomic environments by means of a more fully developed appreciation of mechanistic complexity to obtain a richer understanding of the geometric and electronic structure of practically significant physical systems.

One source of widespread complexity in x-ray spectra arises from the rather copious production of multiple inner-shell vacancies on atomic sites under energetic excitation. Such multiple initial vacancy states are responsible, in large measure, for the widespread occurrence of satellite lines in x-ray emission spectra and for the appearance of structure in absorption spectra not expected on the basis of a single active electron approximation. Evidently the association of these spectroscopic features can be most readily investigated by excitation of emission spectra using monochromatic radiation tunable through the regions of single and multiple vacancy production thresholds.

The implied doubly differential measurements were nearly impossible before the availability of dedicated synchrotron radiation sources such as the National Synchrotron Light Source (NSLS) at Brookhaven. It was for this reason that the Division established and operates a high performance beamline (X24A) at NSLS which has made possible a number of threshold spectroscopic studies as well as opening the way to new areas of molecular orientation, polarimetry and surface structure research. A few aspects of this work will be detailed in the following paragraphs.

The primary beamline monochromator has long been used together with a secondary emission spectrometer for inner-shell studies on gas-phase samples. Selective excitation of x-ray emission provides information on threshold phenomena, including resonant inelastic scattering, the onset of multielectron excited states, and the alignment of core-excited states as revealed by the polarization and anisotropy of x-ray emission. Recently, the evolution of inelastic resonance scattering into x-ray fluorescence was characterized for the case of Xe $L\alpha_{1,2}$ and $L\beta_{2,15}$ emission recorded as the incident x-ray energy was scanned across the L_3 edge. The energies, intensities, and line shapes of the emitted x-rays display variations across the edge in qualitative agreement with the theory of x-ray resonance Raman scattering. The emission spectrometer is currently being upgraded to allow selective-excitation techniques to be applied to a wide range of samples, such as crystalline materials, thin films, and liquids.

An electron spectrometer developed for atomic and molecular studies has been used on the beamline for the first time. The spectrometer makes use of a cylindrical-mirror analyzer at fixed emission angle. The energies, intensities, and line shapes of photo- and Auger-electrons characterize one-electron and many-electron excitation processes and the decay dynamics of core-level vacancies. Initial studies focussed on K-shell excitation of Ar. The K-shell vacancies decay primarily by KLL Auger processes, leaving the atomic ion in double L-vacancy states, which further decay by LMM Auger processes. We have recorded the LMM Auger spectra produced by vacancy cascades and found them to be strongly modified in comparison with the well-known LMM spectrum produced by direct ejection of an L-shell electron. The cascade LMM spectra display strong continua and discrete lines resulting from transitions between complex arrays of multi-vacancy states.

The x-ray standing wave (XSW) technique continues to be a popular and productive activity involving members of the QMD, other NIST divisions, Argonne National Laboratory, Stanford University, University of Washington, IBM Research, and the Naval Research Laboratory. The XSW technique is being applied to a diverse range of structural studies of bulk dopants and surface layers of crystalline materials. This technique is based on the interference pattern established within a crystalline sample by incident x-rays at wavelengths comparable to atomic dimensions. The high intensity and resolution, small focal spot, and particular energy range of beamline X-24A are ideal for such studies.

Considerable effort continues to be given to the development of x-ray optical instrumentation and techniques. A bent Ge(220) crystal was installed in the beamline monochromator and used in conjunction with the focusing mirror to provide an intense, focused beam at high x-ray energies. A multilayer mirror was installed to serve as a power filter to reduce thermal stress on the first monochromator crystal. Both developments provided important experimental information needed for future progress in improving and extending beamline performance.

■ **Microstructural Investigations.** A number of technical and scientific interests currently attach to the behavior of synthetic layer microstructures. To cite but two, such multilayers are important as coatings for high performance optics needed in projection x-ray lithography and x-ray microscopy. Similar structures (though with generally fewer and shorter periods) are of importance for high density information storage and for semiconductor laser and related devices.

We have established a multi-axis x-ray system for investigating such structures using laboratory diffraction sources and making use of techniques already developed for the investigation of the quality of single crystals. This reflectometer/diffractometer system has been operational for the past year and gives exceptionally high quality data. In addition, theoretical investigations have addressed the relationship of multi-layer reflection as seen in the conventional optical perspective with the dynamical theory of x-ray diffraction (see Theoretical Investigations, below). The x-ray characterization investigations carried out in this Division are closely coupled to parallel investigations of the longer wavelength performance of multi-layer mirrors as studied elsewhere in this Laboratory and the magnetic properties of multilayer structures investigated both in this Laboratory and the Chemistry Laboratory.

■ **Spectroscopy of the sun and active galaxies.** We continue a long-standing association with x-ray astronomy from orbiting platforms based largely on Division resources in crystal diffraction technique built up primarily for other purposes. This involvement with spacecraft payloads provides a modest amount of added resources, interesting technical challenges and a window to an important dimension on contemporary research. In earlier times, all the crystal systems carried on the (US) Solar Maximum Mission were characterized in this laboratory and their window-functions evaluated and incorporated into a database. Similarly, crystals carried on P78-1 (the longest running solar spectrometers until the spacecraft was used as an active target in an SDI intercept exercise) came from this laboratory. Most recently we were responsible for several aspects of the four channel Bragg Crystal Spectrometers (BCS) currently in orbit on the Japanese satellite, YOHKOH. In the past year, we have (with NASA support) characterized detectors already flown on the Shuttle (the Broad-Band X-Ray Telescope, BBXRT), and provided star simulation for tests of the ASTRO-D telescope (see Highlights). We are also preparing to deal with the high resolution cryogenic bolometer detectors intended for flight on the Advanced X-ray Astrophysical Facility (AXAF).

■ **Theoretical Studies.** Work in this area evolves with the programs, available personnel, especially visitors, and opportunities for gaining external support. Longest standing exercises have been in the areas of atomic physics calculations of the energy levels and transition energies of atoms containing inner-shell vacancies. This is clearly in the mainstream of our efforts and was significantly advanced during the three-year stay of Paul Indelicato, a visitor from Universite Pierre et Marie Curie. In addition, we have had, from time to time, more fundamentally oriented theorists as staff members. The current incumbent in this area is M. Danos. His present emphasis is on the continued development of the mathematically rigorous quantum field theory, in particular the special requirements associated with gauge theories and other basic physics issues of more general interest (see Highlights).

Theoretical studies of diffraction, reflection and penetration of x-rays and gamma-rays particularly in crystalline and periodic media have been a long-standing theme. Before his departure to Argonne, Paul Cowan was a significant contributor to diffraction theory in general, to discussions of the role of evanescent fields and the maintenance of an optical constants database for the x-ray region permitting prediction of crystal response functions. In the past year, two visitors are having a major impact in these and related areas. Specifically, C. Chantler has made a critical reassessment of the database for scattering factors from well below 1 keV to well above 1 MeV with already some rather surprising results. In addition, another visitor, A. Caticha, provided a rigorous basis of dynamical diffraction theory for an understanding of synthetic layer microstructures (see Highlights).

HIGHLIGHTS

■ **Measurements with NIST Gamma-ray Spectrometer Result in International Workshop.** On October 5-7, 1992, a *Workshop on Applications of High Resolution Gamma Spectroscopy in Studies of Atomic Collisions and Nuclear Lifetimes* was held at the Institut Laue-Langevin (ILL), Grenoble, France. An international collection of sixty-one scientists gathered to hear invited presentations on precision gamma-ray spectroscopy, nuclear lifetimes, and atomic collisions. The external chairman of the workshop was R. Deslattes who was also one of the "lead off" speakers.

The workshop emphasized precision measurements of Doppler broadened gamma-ray profiles and the use of these profiles to determine nuclear lifetimes and atomic collision parameters. The recent interest in Doppler broadened gamma-ray profiles stems from the fact that the small broadening resulting from nuclear recoil can be measured precisely with the NIST high resolution double flat crystal spectrometer. Originally the NIST spectrometer was installed at the ILL to measure high energy gamma-ray wavelengths because the ILL high flux reactor is the only facility in the world which provides intense gamma-ray beams and specialized source changing facilities. The features of the NIST spectrometer which make it a uniquely suited instrument for Doppler broadened profile measurements are the very high resolution (10^5 to 10^6) and the very well characterized instrument function (Fig. 1). More than 20 non-NIST scientists have been associated with the Doppler broadened profile measurements and during the past 2 years 75% of the available gamma-ray beam time at the ILL has been scheduled on the NIST spectrometer.

In the workshop summary talk, delivered by K.P. Lieb of the Universität Göttingen, great

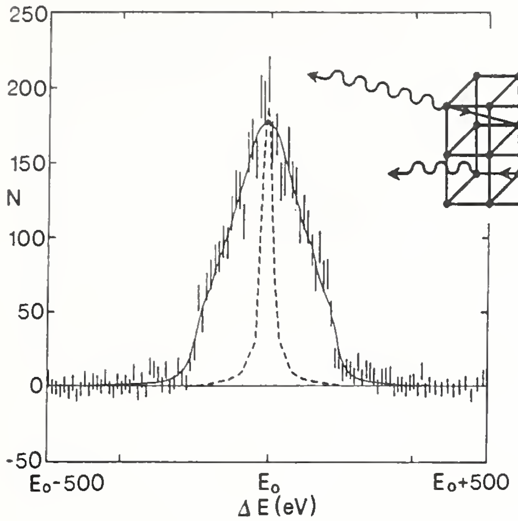


Figure 1. The insert shows the logo used for the International Workshop which was intended to convey the concept that gamma profiles obtained through cascades are determined by the recoil of the anticipatory transition and are modified due to the presence of the material environment and its crystalline structure. The profile shown represents data and a model of the broadened lineshape which includes as one of the main parameters the lifetime of the intermediate state. The result for this case, 15 fs, demonstrates the access of this technique to the critically important regime between the femtosecond and picosecond.

appreciation for the NIST high resolution spectrometer and the access it has provided to new areas of nuclear and atomic collision physics was expressed. (E. Kessler)

■ **Photoion Spectroscopy on X-24A.** The Division has extended its present ability to study photons and electrons emitted during atomic rearrangement to include ion detection. As a result, we have conducted fundamental studies of electron-electron correlation and preformed coincidence measurements of Auger electrons and photoions on NIST's beamline X-24A.

The ratio of helium double-to-single photoionization cross sections has been measured at photon energies from 2 to 12 keV using time-of-flight (TOF) techniques on NIST beamline X-24A and BNL beamline X-26C. These measurements test theoretical models of electron-electron correlation in the simplest three-body atomic system. The NSLS x-ray ring was operated in single-bunch mode during these studies to provide a pulsed x-ray beam suitable for TOF experiments. The results are consistent with an asymptotic ratio $\sigma^{++}/\sigma^{+} \approx 1.5\%$, in substantial disagreement with several recent theoretical predictions. As a result of these measurements, theorists have performed new calculations which help reconcile the differences between theory and our data.

We have measured, for the first time, xenon and argon photoion charge distributions in coincidence with several of the Auger transitions which characterize the initial step of an inner-shell vacancy cascade. Inner-shell vacancies created in heavy atoms percolate up to the outer levels, on the femtosecond time scale, by a complicated series of radiative and Auger transitions. When observed in coincidence with several of the Auger electrons which characterize the first step of the vacancy cascade, photoion charge distributions following argon K-shell or xenon L-shell photoionization show remarkable structure as the incident synchrotron radiation is tuned in energy across the absorption edge.

The advantages of the coincidence requirement are twofold. First, all initial vacancies are established to be in a particular shell, rather than being distributed among many levels. Second, the first step in the decay process is specified. Thus, the photon-energy dependence of the resultant charge distribution becomes more amenable to interpretation. Below threshold, resonant photoexcitation to bound np levels dominates, accompanied by frequent shakeoff of these weakly bound electrons during subsequent decay steps. Far above threshold, shakeoff processes become evident. Between these regimes, postcollision interaction provides a smooth link between complex decays near threshold in which excitation and deexcitation are inseparable and higher-energy processes in which excitation and deexcitation can be treated successfully by the two-step model. (J. Levin and S. Southworth)

■ **Calibrations for X-Ray Astronomy Missions.** This year saw two calibration projects for high energy astrophysics. The first, nearing completion at year's end was a post flight detector evaluation for the silicon x-ray detector assemblies from the Broad-Band X-Ray Telescope (BBXRT) mission that flew on the Shuttle (STS-35) in 1991. BBXRT had a large aperture grazing incidence "objective" consisting of a large number of nested conical foils which "imaged" objects in its field of view on a high resolution lithium drifted silicon detector. Our task has been to produce monochromatic radiation of determined flux levels at a number of discrete energies from 0.5 keV to 12 keV permitting evaluation of the energy calibration curve for the detectors and their resolution. In addition, we provided continuously tunable radiation through the silicon, nickel and gold edges to look for changes in the response of the detector due to the materials of its construction. These results permit more detailed and reliable analysis of the data from the BBXRT mission than would have otherwise been possible.

In the second project, we made a portable and more powerful version of the calibration test stand used in the BBXRT calibration and two staff members took it to White Sands Missile Range in New Mexico. There it was interfaced to one end of a 300 meter (1000 ft) vacuum tank. To the other end were attached telescopes for the ASTRO-D mission due for 1993 launch from the Kagoshima Space Center in Sagamihara, Japan. This major x-ray imaging and spectroscopic spacecraft will carry four of the 40 cm aperture grazing incidence nested cone objective telescopes designed and built by NASA-Goddard and described above. Two of these use solid state imaging spectrometers (MIT) while two others use gas scintillation energy spectrometers (U. of Tokyo). In August and September, we provided full aperture illumination for the 40 cm objectives, permitting evaluation of their image quality, telescope efficiency and effective area for x-rays covering the range from 2 to 12 keV. The detector response to changes in intensity and off-axis illumination was also studied. This characterization prepared the system for its 1.5 year mission, which will include surveys of a wide variety of x-ray emitters including supernovae remnants, x-ray binaries and the diffuse x-ray background. (L. Hudson)

■ **Unified Theory of Multi-Layer Diffraction.** X-ray diffraction measurements are widely used for the characterization of synthetic multilayer structures, indeed, the Division has built and operates a unique and powerful 5-axis diffractometer/reflectometer primarily for this purpose (see last year's highlights). The problem of understanding the actual structure of the multilayer from these diffraction data is, however, considerable since key assumptions of all convenient approximations are violated in some important regions of the diffractogram. A recently departed visitor (A. Caticha, now on the faculty of the Physics Department SUNY, Albany), has completed an exceptional synthesis of the methods used in optics (Fresnel description of multilayer mirrors) and those commonly employed for the description of x-ray diffraction by crystals, in particular, the dynamical diffraction theory of Ewald and von Laue. The result, a new version of the Darwin diffraction theory, is a unified, intuitively satisfying and computationally efficient procedure that accurately reproduces even rather delicate features of the diffractogram over more than six decades of reflectivity.

Most multilayer diffraction modeling has proceeded from the Fresnel description of reflection and transmission of light by a smooth interface as found for example in Born and Wolfe. Multilayer diffraction is obtained in an iterative formulation considering phase-delayed fields incident, transmitted and reflected due to the effect of preceding and following interfaces on the fields with which they are presented. While there are no approximations inherent to this approach, diffuse boundaries, a reality in the x-ray region, can only be approached rigorously by dividing them into a number of sublayers for each of which the process needs to be applied as above. Such procedures easily become computationally intensive and, it is probably fair to say, the results are often not physically satisfying. Crystal diffraction theories come in two flavors, kinematical (a first Born approximation) which appeared to be applicable (but is not) in the region between diffraction peaks and dynamical which is clearly required near the peaks where the scattering is strong.

Caticha's contribution has been to elucidate these problems and offer a new approach which is very appealing and already of considerable practical utility. In this, he obtains a rigorous solution to the case of scattering by a bi-layer; it turns out that even here there are problems with approximations but these can be addressed. His bi-layer result allows for both multiple scattering effects within the bi-layer and the presence of diffuse boundaries; in the case that these diffuse boundaries are Fermi functions (the so-called Epstein profile), the resulting reflectivity can be expressed in closed form in terms of Gamma functions (Fig. 2, top). Given this result, the remainder of the calculation can be cast in the form of Darwin's approach to dynamical diffraction, namely the multilayer (or crystal) is taken as an assembly of plane (possibly thick) mirrors separated by vacuum gaps (which are, in the present case made to vanish in the end) (Fig. 2, bottom). (A. Caticha and R. Deslattes)

■ **Non-Invasive High Voltage Measurement for Radiology.** General improvement of image quality for mammography has been shown to require more accurate control and measurement of x-ray

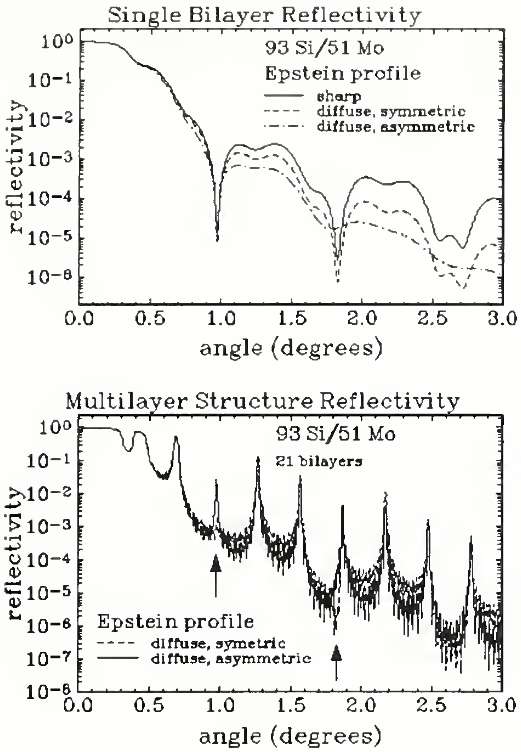


Figure 2 – Reflectivity of (top) one thick single bilayer and (bottom) 21 bilayers (93 Å of Si and 51 Å of Mo) with sharp and diffuse boundaries. Diffuse boundary curves are shown for Si-Mo and Mo-Si interfaces having equal thickness of 5 Å (symmetric) and different thicknesses of 5 Å and 10 Å respectively (asymmetric).

source voltage than is available through current non-invasive methods such as penetrameters and filter packs. Although the needed refinement is, of course, accessible through traditional (invasive) measurements using high potential dividers, there are complications due to the wide range of frequencies and voltage waveforms which must be accommodated. In response to this situation, we devised an alternative approach using moderate resolution wavelength dispersive diffraction spectroscopy, constructed a prototype system and demonstrated that it can achieve the needed precision and accuracy. This approach (which is readily generalized for measurements throughout the range of radiological and radiographical x-ray imaging) will be presented at an international workshop planned for early March, 1993 (see report of Division 846) and is the subject of a current patent application.

The principle of the measurement can be appreciated by referring to the frontispiece which shows an adaptation of a spectrographic geometry originally applied by Rutherford and Andrade for diffracting the gamma-rays of Radium-B and Radium C in 1914. The figure shows the prototype device in which the small x-ray tube focal spot defines the source. The symmetrical Laue diffraction crystal produces two images of the spectrum of the source symmetrically disposed with respect to the centerline or zero wavelength position (Fig. 3). A wavelength

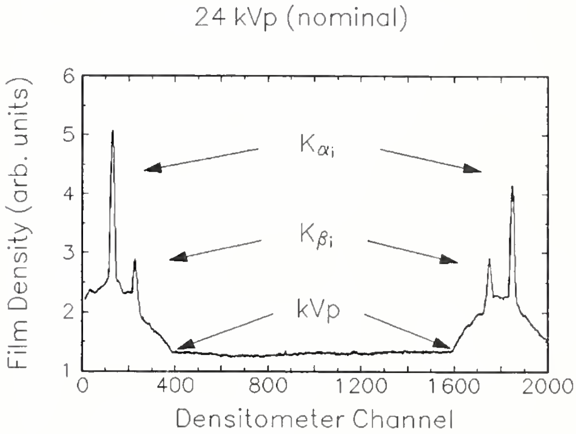


Figure 3 – Densitometer trace of film exposed to radiation from a molybdenum x-ray tube using spectrograph illustrated on frontispiece. Positions of K_α and K_β lines establish energy scale, permitting accurate determination of peak tube voltage, kVp.

λ contained in the source spectrum will appear at two points in the "focal plane" separated by a distance equal to the camera length L multiplied by twice the tangent of the diffraction angle ϑ which is, in turn, the Bragg angle or $\arcsin(\lambda/2d)$ where d is the interplanar spacing.

In particular, at the high frequency limit of the continuous spectrum, photons are emitted with the full energy, E, of the incident electrons, namely $E = eV = hc/\lambda$. The spectrograph is thus an absolute instrument requiring only a measurement of a length ratio in order to establish the x-ray tube voltage without reference to any external standardization. In practice it is more convenient to note the locations of the characteristic emission lines of the target and use these to indirectly establish the camera length. (R. Deslattes and J. Levin)

■ **Entropy in Quantum Physics.** Both in statistical physics and in thermodynamics the second law has axiomatic character. In thermodynamics it must be postulated; it has resisted numerous attempts of proving it. Furthermore, non-equilibrium systems are not really accessible to thermodynamic treatment. In statistical physics one also needs an auxiliary axiom, e.g., the equal-a-priori-probability hypothesis, in order to derive the second law. This way thermodynamics is in a sense a special subject outside of the general physics.

In quantum physics entropy was defined by J. von Neumann around 1930. Rather soon thereafter it was recognized that a state having zero entropy will remain so forever, even though it may have an arbitrary energy content. Evidently this is also not a satisfactory situation.

This difficulty has been resolved by proposing that the entropy in quantum physics be defined in terms of the reaction probabilities which are to be computed by the well-known rules of quantum physics, for example by the Fermi Golden Rule. The so defined entropy, without any auxiliary axioms, has the following characteristics and consequences: (1) It is valid generally, for microscopic and macroscopic systems and hence does not need an ensemble for its definition; (2) It is valid for arbitrarily off-equilibrium systems; (3) The entropy of closed systems can only increase until the system reaches equilibrium; (4) At equilibrium the system entropy agrees with the Boltzmann entropy; (5) Except for harmonically coupled harmonic oscillators the probability that a system undergoes time-reversal invariant motion has measure zero; (6) The second law of thermodynamics, hence thermodynamics itself, is a consequence of quantum physics. (M. Danos)

FUTURE DIRECTIONS

■ **The Visible to Gamma-Ray Connection**. Several developments are anticipated over the coming years in our long-standing, and still unique program for bootstrapping the visible iodine stabilized HeNe laser wavelength (which is well connected with current definitions of length and frequency as well as the Rydberg constant) to the gamma ray region with high accuracy. In the current directions section the three components of this program 1) the XROI measurement, 2) the Δd measurement, and 3) the angle measurements are briefly described. It is anticipated that this program and its progeny will continue to be a major component of our future activity especially with anticipated improvements in the robustness of the first two steps, increasing need for reference spectra for high-Z few electron spectra (described below) and for exotic atom spectra, the need for a new table of x-ray wavelengths (see below) and the expected restart of the Grenoble reactor (where our gamma-ray program resides) in mid 1994. We summarize the status and outlook for the principal components of this program in the following paragraphs.

The main x-ray and optical interferometric aspects of the XROI experiment, though subject to occasional problems and benefiting from continuing improvements, have operated for several years with a reproducibility and stability capable of supporting 0.01 ppm measurement of the silicon crystals spatial period. However, an auxiliary polarization encoded Michelson optical interferometry system, required for monitoring deviations from rectilinear motion, has proven to be more troublesome. Even though the total corrections required for residual trajectory errors are only at the 1 ppm level, the required interferometric sensitivity is nonetheless challenging since 0.01 milli-fringe interpolation is required to achieve the needed 0.1 nanoradian sensitivity. Data analyses show that the needed signal to noise ratios are easily realized and that stability is, perhaps surprisingly, not an issue. Instead, we have encountered systematic errors with multi-fringe periods which have proven unexpectedly difficult to understand and correct. In recent months, two possible sources of these puzzling effects have been identified and remedial measures undertaken including re-figuring of a complex polarizing beamsplitter and introduction of unique Brewster angle beam separators. Although the results of these remediation efforts are not yet available, our conviction that this is a soluble problem remains strong.

The silicon sample measured in the XROI experiment needs to be compared to other crystals used for precision x-ray and gamma-ray wavelength measurements. The delta-d spectrometer which is used for the comparison measures the small difference in Bragg angle between the standard sample and the unknown. The thickness of the samples is carefully chosen in order to introduce Pendellosung oscillations on the profiles, thus making profile division more accurate. There are six silicon samples and three germanium samples associated with the GAMS4 spectrometer at the ILL and the transmission spectrometer in the Radiation Physics Building which need to be compared to the standard silicon sample. The activity in this area in the next year will be concentrated on the preparation of crystalline samples of the appropriate thickness (currently 0.45 mm) and the measurement of the Bragg angle differences between the standard sample and the unknowns. We plan to have these comparisons in hand before the GAMS4 spectrometer is reinstalled on the ILL reactor floor.

The GAMS4 spectrometer and the newly recommissioned transmission spectrometer in the Radiation Physics Building are quite similar although not exactly identical. Small diffraction angles are measured with heterodyne interferometers and the crystal rotations are absolutely calibrated by using an optical polygon. In order to achieve 0.1 ppm accuracy at 2 MeV, an interferometer fringe must be divided into ~4000 parts. This is a significant challenge especially for an instrument with a range of 30 degrees and can only be achieved if the spectrometer is well isolated from environmental disturbances. We continue to improve the angle interferometry on both spectrometers and on off line test interferometers. Fringe non-linearity has been reduced to about 0.001 fringe and further reduction is expected by using heterodyne interferometry in which the two frequencies are generated by acousto-optic modulation. Modifications to the spectrometer to make it more tolerant of vibrations and improvements to the thermal and vibration isolation systems are being made. The ILL high flux reactor which has been off line since mid 1992 for repair is scheduled to go on line in mid 1994. We plan to have completed all the improvements before the GAMS4 spectrometer is re-installed on the reactor floor in 1994.

In parallel with spectrometer improvements, high-Z x-ray wavelength measurements will soon begin at the Radiation Physics Building. Our goal is to measure the intense K series lines for some of the elements with $90 \leq Z \leq 96$, the region where theory and experiment are most discordant. In addition, these measurements will contribute to the x-ray wavelength table project (see below).

■ **Progress Toward a More Accurate X-ray Wavelength Table.** The widely used Table of X-ray Wavelengths by J.A. Bearden is seriously flawed by an inconsistent reference scale, an obsolete base unit, some line misidentifications, and dependence on poorly documented measurements, some carried out more than 60 years ago. Over the years we have received numerous requests (individual scientists and the International Union of Crystallography) to provide a more accurate x-ray wavelength table. In the past we have responded to these requests by accurately measuring selected x-ray wavelengths using double flat crystal technology. This technology includes accurately calibrated angle-measuring spectrometers equipped with crystals whose lattice spacings are linked with the current definition of length by simultaneous x-ray and optical interferometry of a common baseline.

We are now in a position to begin a more systematic approach leading to a more accurate x-ray wavelength table. Our approach involves new accurate measurements of the intense lines over a wide range of Z. The density of measurements is anticipated to be about 1 for a ΔZ of 5. The experimental measurements will then be compared with sophisticated theoretical calculations in order to derive corrective factors which are expected to vary slowly and smoothly with atomic number. Experimental values for unmeasured lines will then be estimated from theoretical calculations corrected by the previously determined factors. During the past year two crystal spectrometers have been upgraded to provide greater accuracy and ease of use. They are a double flat crystal vacuum spectrometer for measurements from 1 to 20 keV and a double flat crystal transmission spectrometer for measurements from 20 keV and higher. The theoretical tools needed for this task have been developed over the past years by external collaborators, primarily P. Indelicato from the Universite Pierre et Marie Curie. Comparison of these calculations with a highly selected data set shows corrective factors which vary smoothly with Z for the intense K series transitions.

■ **Enhanced Performance of beamline X-24A.** Efforts will continue to improve beamline performance. Of central importance will be the development of multilayer-mirror technology to limit the heat load borne by the first monochromator crystal. The resultant improvement in photon-energy resolution will benefit many experiments in which subtle effects near atomic absorption edges are probed. Further gains can be expected from higher photon flux expected from employment of curved monochromator crystals.

These improvements in beamline energy resolution and flux will permit more-detailed studies of vacancy cascades. The decay of a single inner-shell vacancy in a heavy atom can produce many electrons, photons, and a highly charged residual ion. Understanding the complex paths by which the vacancy cascade proceeds can best be accomplished by examining the atomic fragments in coincidence, with an attendant decrease in count rate. Substantial success has already been achieved in coincidence studies of photoions and Auger electrons. It is expected that the present program will be extended, using newly available avalanche detectors, to measure coincidences of photoions or Auger electrons with fluorescence photons. The resultant charge distributions will provide information complementary to that obtained in photoion Auger-electron measurements.

■ **Support of Future X-Ray Astronomy Missions.** Our Division has long made significant contributions to national and international space ventures involving the detection of solar and high-energy x-rays. We continue a collaboration with NASA which employs the techniques of x-ray production and detection which we have pioneered while also providing enhanced financial base for other division activities. In particular, in 1993 we begin a program of preflight calibration of microcalorimeter detectors in support of the Advanced X-Ray Astrophysical Facility (the AXAF project). These will be used to detect very faint cosmic x-ray sources with an energy resolution unprecedented in x-ray astronomy (≈ 10 eV).

■ **X-Ray Technology/External Interactions.** In keeping with the evolving expectations that work in the NIST laboratories should connect with industrial needs, we have begun to enhance such interactions. In addition, we are attempting to be of service to the health care community (see Highlights) in regard to standardization of radiation quality for diagnostic radiology. On the industrial side, we have one active CRADA with X-ray Optical Systems in the area of optical control of x-ray beams and are attempting to develop additional linkages consistent with resource limitations and technical orientation.

As in the case of our long-standing association with work in support of x-ray astronomy programs, these external connections are based on the technology developed in the Division for study of x-ray spectra both in this laboratory and at our off-site installations. Toward the future, we see particular opportunities for the transfer of technology developed in the astronomy community to problems in radiation management and utilization in industrial and medical applications.

Aside from the obvious appropriateness of responding to changes in institutional outlook, and the occasional opportunities for securing external support, we find that these efforts are both challenging and rewarding in themselves. They bring us into contact with new problems and provide occasions for enhancing the technological resources that are available for our more traditional efforts and for further applications.

■ **Spectroscopy of Few-Electron Ions.** We are continuing a long-term program to measure $\Delta n \geq 1$ transitions in selected hydrogen-like and helium-like ions as part of an effort to systematically check the quantum electrodynamical (QED) contributions to the transition energies in few-electron ions. The most ambitious part of this program will study the upper end of the periodic table in the heavy-ion Experimental Storage Ring (ESR) at the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt, Germany. We will make use of the unique abilities of the ESR to accelerate ions up to and including uranium to high enough energies to strip away efficiently all or nearly all electrons, to decelerate the ions back to low enough velocities to minimize Doppler effects, and to cycle the heavy-ion beam repeatedly through a gas target to obtain usable counting rates while reducing the background from excited spectator states.

The x-ray transition energies will be measured by one of two methods, both of which exist as accepted proposals to the Scientific Committee of GSI. Our ultimate goal is to measure the x-ray transition energies at the several parts per million (ppm) level using crystal spectrometers, allowing us to check the Lamb shift contributions to these transitions at the level of several tenths of a percent. This level of accuracy matches that of theoretical calculations of the QED contributions to these transition energies and will provide a critical test of the theory, but will first be possible in coming years when the ESR reaches its design intensities. In the meantime we will use the technique of Doppler-tuned spectrometry to measure to a few tens of ppm, already an improvement of orders of magnitude over existing measurements. The general feasibility of these methods has been verified in preliminary measurements already carried out at GSI (of x-ray transitions in hydrogen-like dysprosium). In both cases an absolute calibration of the transition energies will be made by using techniques and facilities unique to our Division. In the case of the crystal-spectrometer measurements, we will use x-ray transitions in neutral atoms as transfer standards and in the case of the Doppler-tuned spectroscopy we will use atomic absorption features of thin metal foils. These in turn will be calibrated using crystals whose spacing are know through x-ray/optical interferometry in terms of the Rydberg constant, as described above.

At the lower end of the periodic table, we will continue existing programs at the linear accelerator at Argonne National Laboratory. A measurement of the n = 2 to n = 1 x-ray transitions in helium-like calcium to an accuracy of several tens of ppm is planned for this spring. In order to bridge the gap in availability of one- and two-electron ions between that provided by linear accelerators such as Argonne and storage rings such as GSI we also plan to measure $\Delta n \geq 1$ transitions in selected hydrogen-like and helium-like ions in the atomic number range $30 < Z < 60$ with the Electron Beam Ion Trap (EBIT) being assembled on site in the Physics Building. We will measure the transition energies with crystal spectrometers to an accuracy of several ppm, providing a check of the Lamb shift contributions to these transitions at the level of several percent. ▫

IONIZING RADIATION DIVISION

Overleaf

Water-Sphere Neutron Leakage Benchmark. Measured fission rates for four fissionable isotopes – ^{235}U, ^{239}Pu, ^{238}U, and ^{237}Np – are compared with detailed Monte Carlo calculations for the neutron field outside spherical water moderators that surround a ^{252}Cf fission neutron source. Two NIST double fission chambers are shown on opposite sides of a thin-walled, water-filled sphere of stainless steel. The ^{252}Cf neutron source capsule is shown above the sphere before insertion. This benchmark tests criticality safety calculations for the processing and storage of fissionable isotopes in aqueous solution.

IONIZING RADIATION DIVISION

MISSION

The Ionizing Radiation Division of the Physics Laboratory has the responsibility within NIST for providing national leadership in promoting accurate, meaningful, and compatible measurements of ionizing radiations (x rays, gamma rays, electrons, neutrons, energetic charged particles, and radioactivity). The Division:

- provides primary national standards, dosimetry methods, measurement services, and basic data for application of ionizing radiation to radiation protection of workers and the general public, radiation therapy and diagnosis, nuclear medicine, radiography, industrial radiation processing, nuclear electric power, national defense, space science and environmental protection;
- conducts theoretical and experimental research on weak interaction physics and fundamental quantum physics and on the fundamental physical interactions of ionizing radiation with matter;
- develops an understanding of basic mechanisms in radiation particle tracks, and associated stochastic processes in the microscopic absorption of radiation by chemical and biological systems, which will lead to predictions of endpoints for radiation-induced effects;
- develops improved primary radiation standards, and produces highly accurate standard reference data for ionizing radiation and radioactive materials;
- develops and provides standard reference materials (SRMs), calibrations, and measurement quality assurance services to users such as hospitals, industry, States and other Federal agencies; and
- develops and operates well-characterized sources and beams of electrons, photons, and neutrons for primary radiation standards, calibrations, research on radiation interactions, and development of measurement methods.

To accomplish these goals, the Division staff interacts widely in the national radiation community in all sectors including industry, State and Federal government, and universities. The Division has strong interactions in the international radiation community through scientific collaborations and committee activities. Division staff members participate in numerous professional societies and on many committees. The Division is collaborating with 18 organizations in the radiation community in the establishment of the Council on Ionizing Radiation Measurements and Standards (CIRMS).

ORGANIZATION

The Division employs about 50 scientists, engineers, technicians and secretaries. Activities include fundamental research, applied research, and a wide variety of measurements services. The group structure consists of three technical groups (Radiation Interactions and Dosimetry, Neutron Interactions and Dosimetry, and Radioactivity), together with the Office of Radiation Measurement which is our primary outreach group to the radiation user community and the secondary laboratory system.

CURRENT DIRECTIONS

- **Transfer Standards for Neutron and Radiobioassay Secondary Laboratories.** We are carrying out research, development, and evaluation of transfer standards to meet requirements for proficiency testing of neutron and radiobioassay secondary laboratories.
- **Measurement Quality Assurance for Environmental and Radiobioassay Laboratories.** The Office of Radiation Measurement is focussing on the development of measurement quality assurance programs for environmental and bioassay radioanalytical laboratories.
- **Medical-Industrial Radiation Facility.** There are urgent requirements by U.S. industry for collaborative research and support of electron-beam processing of advanced materials, and by the U.S. medical community for high-energy electrons and photons to develop new protocols

for dosimetry in medical therapy. Our plan is to address both needs with an accelerator-based user facility at NIST. The installation of the 32-MeV Sagittaire linac is a top priority.

■ **Electron Paramagnetic Resonance Dosimetry.** The Ionizing Radiation Division is leading a national and international effort in electron paramagnetic resonance (EPR) dosimetry for measurements of ionizing radiation. With NIST leadership, alanine/EPR dosimetry is expected to provide a high-accuracy, low-cost method for quality control of radiation processing and sterilization.

■ **Bone Dosimetry.** NIST is also pioneering in efforts to measure absorbed dose to bone and tooth enamel, with applications in food irradiation, accident dosimetry, and dosimetry for injected radiopharmaceuticals. The current approach involves external irradiation of bone samples with monoenergetic electrons and photons, calculations of depth dose profiles, and EPR measurements of radiation-induced free radicals.

■ **Neutron Dosimetry for Materials Performance Assessment.** To advance NIST goals of regulatory assistance, and the leveraging of industry developments in technology, we are improving diverse, innovative dosimetry methods for monitoring the degradation of materials exposed to high neutron fluences.

■ **Investigations of Fundamental Symmetries With Low Energy Neutrons.** On-going and planned experiments will test either fundamental symmetry laws (i.e., time reversal non-invariance) or fundamental physical laws (i.e. the "standard" model of the electro-weak interaction). These experiments are carried out at the CNRF where the novel properties of "cold" neutrons can be exploited. The NIST effort in this area of fundamental physics involves a number of collaborative projects with National Laboratories and Universities.

■ **High-Accuracy Determination of Neutron Flux.** The development and implementation of advanced methods to accurately determine low energy neutron flux will provide a primary standard for neutron dosimetry, for target assay in prompt-gamma isotopic analysis, and for the calibration of the NIST National Standard Neutron Source. First application of this capability will be to recalibrate apparatus used in the determination of the free neutron lifetime.

■ **Radionuclide Standards for Nuclear Medicine.** The exciting application of many radionuclides as targeted therapeutic agents in nuclear medicine has brought many demands for national standards and improved decay data before the clinical research phase. These are being addressed in collaborative measurements involving the Radiation Interactions and Dosimetry and Radioactivity Groups.

■ **Radon Measurement Intercomparisons.** Integration of national radon standards into the worldwide atmospheric monitoring system is underway. An intercomparison with radon gas samples distributed from NIST has evaluated the agreement among U.S. reference laboratories and several foreign reference laboratories, and radium "capsules" which quantitatively emit radon have been extensively tested in preparation for distribution as SRMs.

HIGHLIGHTS

Office of Radiation Measurements

■ **Secondary Calibration Laboratories for Ionizing Radiation.** This is a calibration laboratory accreditation program administered by the National Voluntary Laboratory Accreditation Program at NIST with technical support from the Office of Radiation Measurements. Official accreditation was granted to the Center for Devices and Radiological Health (CDRH, USFDA) for calibrations with three x-ray beam qualities. CDRH is the first laboratory in the program to receive accreditation. Two other laboratory applications for accreditation have been received; an additional 7 laboratories show strong potential for acceptance in this program. (J.C. Humphreys and M.D. Walker)

■ **Development of Transfer Standard Instruments for Personnel Dosimetry.** The suitability of selected types of TLDs and commercial remmeters for use as neutron dosimetry transfer standards was determined. Measurements have been made at NIST and PNL to determine the effects of differences in the neutron spectra of the bare and moderated Cf sources at the two facilities. Also, the beta dosimetry calibration program acquired a set of calibrated beta-particle sources and a specially-built extrapolation chamber to enable NIST to provide high-accuracy testing of secondary calibration laboratory beta sources and ionization chambers. (J.C. Humphreys and M.D. Walker)

■ **Evaluation of Secondary Transfer X-ray Instruments for Performance Testing of Secondary Laboratories.** Response evaluations of the commercially available PRM MC3 parallel plate ionization chamber demonstrated a significant difference of the geometric center from the effective center of the chamber. The position of the effective center of the chamber is linearly sensitive to the quality of the beam (half-value layer). These results indicate that calibration of this type of ionization chamber requires careful characterization of the x-ray beams. Furthermore, widespread use of this type of ion chamber in situations other than those used during the calibration must be accompanied by corrections to account for the position of the effective center within the instrument. (M.D. Walker)

■ **Calibration of a New National X-Ray L100 Beam.** In collaboration with the Radiation Interactions and Dosimetry Group a new L100 x-ray beam quality was established and calibrated. The L100 beam (lightly filtered, 100-kV tube potential) was developed to decrease the need for extrapolation or interpolation of x-ray beam qualities by the radiation end user. The L100 beam is used for calibrating ionization chambers that measure the radiation output of diagnostic x-ray equipment. (M.D. Walker and P.J. Lamperti)

Radiation Interactions and Dosimetry

■ **Medical & Industrial Radiation Facility (MIRF).** In addition to the existing x- and gamma-ray sources, a new medical and industrial radiation facility (MIRF) is being developed for research at higher electron and photon energies. The heart of this facility is a 32-MeV electron linac which was donated to NIST in 1992 by the Yale University New Haven Hospital. The accelerator was dismantled and shipped from New Haven by Group personnel. This accelerator is currently being reassembled in the Radiation Physics Building. The machine is designed to operate at voltages from 7 to 32 MeV in 3-MeV increments and has provisions for a high-energy photon mode at 25 MeV. Presently, the main accelerator sections and the beam handling systems have been installed and are under vacuum. (C.E. Dick, M.R. McClelland, and B.M. Coursey)

■ **High Dose Cobalt-60 Facility.** In October a new ^{60}Co GammaCell 220 was installed as the main gamma-ray irradiator in a new user facility for research and calibrations. The self-shielded irradiator contains 24 kilocuries of the ^{60}Co radionuclide. This very strong gamma-ray source gives NIST the capability of irradiating samples with a dose rate of 5 grays per second.

The GammaCell irradiators are used to administer accurate gamma-ray doses to transfer and reference standard dosimeters such as radiochromic films and alanine, which are used in the NIST high-dose calibration services. The main users are in the areas of industrial radiation processing and medical device sterilization. These irradiators are also used by a number of other NIST laboratories for radiation-hardness testing of electronics, polymers research, radiation chemistry, and the study of radiation-induced changes in biomolecules. The new facility is also equipped with modern spectrophotometers, laser scanning densitometers, and associated computers for reading irradiated radiochromic films. (M.L. Walker, J.M. Puhl, and J.C. Humphreys)

■ **Electron Paramagnetic Resonance (EPR) Dosimetry Facility.** EPR is used as a nondestructive probe of the structure and concentration of paramagnetic centers. The centers created by ionizing radiation are proportional to the absorbed dose, and provide a sensitive and versatile measurement method. The EPR dosimetry facility is supported by two state-of-the-art X-band EPR spectrometers capable of measuring radiation effects on a wide range of inorganic and organic materials. Each data acquisition system provides full computer control of all spectrometer functions, including real-time spectral display and rapid acquisition scan to analyze decaying signals. Each data acquisition system is interfaced with an advanced data analysis workstation for data manipulation, spectral simulation, and multi-component spectral deconvolution. (M.F. Desrosiers and others)

■ **Space-Shielding Radiation Dose Calculations.** A computerized database and code package is being developed for the routine prediction of the absorbed dose from incident electrons and their secondary bremsstrahlung, and from incident protons, as functions of the thickness of aluminum shielding of structures in space. This work represents a thorough updating, extension, and refinement of our earlier SHIELDOSE package, which has found wide use in the space-radiation-effects community.

The preparation of the database has involved extensive Monte Carlo calculations of the penetration, scattering and energy loss of electrons in aluminum slabs, the production of secondary bremsstrahlung, and the penetration and scattering of these photons to greater depths. The proton dose distributions have been evaluated in a simple straight-ahead approximation. The user code will rapidly perform the necessary interpolation over the database and the integration for any specified spectra of incident electrons and protons, giving the distribution in a variety of simple geometries of dose in small detector volumes of Al, graphite, Si, air, bone, CaF_2, LiF, GaAs, SiO_2, tissue, or H_2O. (S.M. Seltzer)

■ **Electron Irradiations for Research and Industry.** In the past year, the emphasis in the use of the particle accelerators has been on electron production and interactions. These uses are divided into three principal categories; development of new dosimetry methods; materials modification; and performance testing. Principal advances have been made in the development and characterization of radiochromic dye dosimeters, alanine dosimeters, and an electron beam calorimeter for absolute measurement of the dose delivered by 2 to 8 MeV electron beams.

Additionally, the electron Van de Graaff has been extensively used in experiments to modify the structure of polymeric materials to increase fire resistance. Other materials are being irradiated to increase their neutron scattering properties to develop a new type of neutron detector. Electron exposures have also been made of bone samples to assist in the development of post-irradiation dosimetry. Finally, the electron beam has also been used to investigate the radiation response and damage induced in silicon solar cells designed for space uses. (C.E. Dick)

■ **Dosimetry of High-Energy Electron Beams.** Accelerator-produced high-energy electron beams, 4 MeV to 12 MeV in energy, are now widely used in the industrial sector to sterilize medical devices and instruments, crosslink polymers and composites, induce color centers in gems, eliminate microorganisms in certain meats, and extend the shelf life of fruits. A set of novel calorimeters has been designed that will allow the direct measurement of the radiation dose delivered by electron beams and the calibration of films for routine use with these accelerators. The calorimeters consists of arrays of graphite disks into which temperature-sensing thermistors have been embedded. The calorimeters have now been tested with 2.5-MeV electron beams at NIST, 4.5-MeV electron beams at the University of Maryland linac, and with 9.4-MeV electron beams at Risø National laboratory in Denmark. (M. L. Walker, J.C. Humphreys, J.M. Puhl, C.E. Dick, and W.L. McLaughlin)

■ **Development of Radiochromic Films for Novel Applications.** In a strong collaboration with industry, NIST is working with International Specialty Products, Inc, a subsidiary of General Airline Film Corp., to develop new applications in radiation dosimetry and radiographic imaging. The newly developed "GafChromic" films are meeting crucial measurement needs in several medical, agriculture, and industrial areas, and are showing striking advantages over potential overseas competitor's products from Japan and Europe.

Examples of new world markets developed during 1992 are in brachytherapy and particle-beam therapy, blood irradiator dosimetry for blood banks, food irradiation dosimetry, validation of radiation sterilization procedures, non-destructive evaluation of materials and electron beam processing of polymers. Newer film types are under study in order to broaden the applications for radiation protection and environmental radiation diagnostics. (W.L. McLaughlin, C.G. Soares, and M.L. Walker)

■ **The NIST High-Purity Sealed Water Calorimeter.** Extensive investigations of the NIST absorbed dose sealed-water calorimeter showed that high-purity water saturated with N_2 or H_2 gave results in good agreement with previous measurements made with graphite, graphite-water and a polystyrene-water calorimeter. Measurements made with water saturated with H_2 and O_2 showed significant variations with accumulated absorbed dose. A previous NRC Canada publication considered this system as a reliable standard. As a result of the NIST investigations, the NRC group re-calculated the radiation chemical effects for that system. Their theoretical results are in general agreement with the NIST measurements. The H_2 system appears to be the best both theoretically and experimentally. (S.R. Domen)

■ **Stereotactic Radiosurgical Treatment Planning.** Collaborations with several hospitals (Mayo Clinic, University of Louisville, University of Kentucky, University of Pittsburgh) engaged in "Gamma-Knife" or accelerator beam stereotactic surgery have lead to a novel experimental method that supplements computer-generated treatment planning routines. This involves the use of radiochromic films to map with high spatial resolution the dose-distribution in this treatment volume corresponding to deep-seated lesions. The collaborative work has shown that the three-dimensional images created in the film from stereotactic treatment beams can be analyzed with accuracy and precision by a laser-scanning microdensitometer. Furthermore, this method shows close agreement with computer modeling of treatment dose and dose placement and an improvement over state-of-the-art experimental approaches (e.g., ionization chambers, thermoluminescent dosimeters, semi-conductor probes and radiographic-emulsions) in that it gives high resolution and close simulation of biological tissue response characteristics. (C.G. Soares and W.L. McLaughlin)

■ **Reference Dosimetry for the Intercomparison of Proton Beams in Radiation Therapy.** Cancer therapy studies using high-energy proton beams are underway in several major medical centers in the United States, including the Harvard Cyclotron and a new dedicated medical accelerator at Loma Linda University in California. Russian medical centers, including one at the Institute for Theoretical and Experimental Physics (ITEP) in Moscow, have been investigating proton therapy for two decades. The National Cancer Institute (NCI) is studying the Russian experience in design of new clinical trials for the United States.

The NIST Ionizing Radiation Division is collaborating with the Radiation Research Program at NCI in developing new dosimetry systems to facilitate intercomparisons between these laboratories. Preliminary work has focussed on investigations of alanine-EPR and radiochromic films for use in measuring detailed proton dose and depth-dose curves in high-energy proton beams (Fig. 1). The initial irradiations were carried out in Moscow. Dose measurements and depth-dose profiles obtained from alanine samples read out at the NIST EPR facility agreed with the ITEP values to within ± 5% of the ITEP values for samples irradiated to 100 Gy with 200-MeV protons. More recently measurements have been made with the Harvard Cyclotron. Accelerators at Loma Linda and in St. Petersburg will be included in the next round of measurements. (B.M. Coursey, C.E. Dick, M.R. McClelland, W.L. McLaughlin, M.F. Desrosiers, J.M. Puhl, and D.A. Schauer)

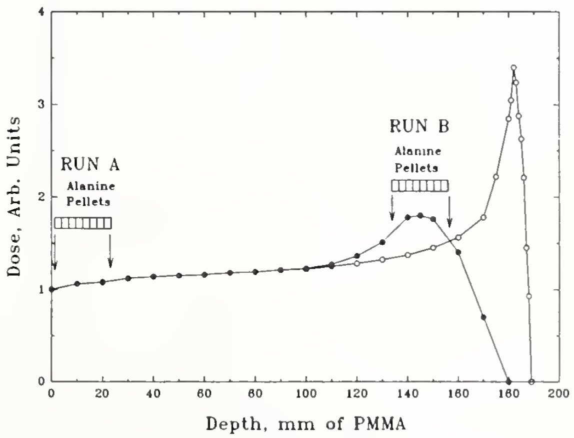


Figure 1 – Calculated depth-dose profiles for the 200-MeV proton beam at the ITEP accelerator. The location of the alanine dosimeter stacks is indicated by the boxes: ○ Run A, alanine at the entrance beam; ● Run B, alanine in the spread out Bragg peak.

■ **Proton Monte Carlo Code Development.** Proton beams, because of their highly-focused pattern of energy deposition, are increasingly employed for radiation therapy in treatment of certain tumors where it is important to spare adjoining critical structures. A Monte Carlo calculation of the spatial pattern of absorbed dose and proton fluence spectra has been developed for conditions of interest in proton therapy. The work includes development of data describing the distribution of secondary heavy charged particles produced in nonelastic interactions by the protons with constituent nuclei in water and tissue, and an investigation into their role in the biological effects of such beams. (M.J. Berger and S.M. Seltzer)

■ **X-Ray Spectral Measurements for Mammography.** Mammography x-ray machines produce ionizing radiation at average energies of between 24 and 32 kV peak voltage. Low energy x-rays are required to detect calcification and soft tissue abnormalities in breast tissue. Because a change of as little as 1 kV affects image quality and dose for these examinations, stringent regulations are being developed for the control of these parameters. However, no method exist for assuring kV accuracies at this level. As a result of the concern that has been voiced by the radiation measurement community, NIST has been requested to establish a calibration standard for instruments to evaluate the accuracy of indicated mammographic kVp energies. To seek a consensus on the directions for a U.S. national standard, NIST has organized a workshop to be held at NIST on March 1 and 2. Participants will represent all of the concerned federal and state agencies, as well as universities and industry. (M.D. Walker and C.G. Soares)

■ **Performance Characteristics of Backscatter Tomographic Systems.** Studies of the performance characteristics of a new type of x-ray scanner are in progress. This scanner detects scattered x-rays and acquires tomographic images from one side of the inspected object. The scanner characteristics are described by the spatial resolution, the density discrimination, the penetration depth in the inspected object for different materials and sizes, and the scan time. The scope of the work is to determine the dependence of these characteristics on the power output and spectral composition of the x-rays for different kilovoltages and filtration of the x-ray machines or of the gamma rays from ^{137}Cs or ^{60}Co kilocurie radioactive sources. (J.W. Motz, C.E. Dick, and M.R. McClelland)

■ **Reconstruction Dosimetry for the Maryland Accelerator Accident.** In December 1991, a radiation overexposure occurred at an industrial electron-beam processing facility in Maryland. An operator violated safety procedures, and placed his hands, feet, and head in a high-energy electron beam resulting in severe disability. At the request of the State of Maryland officials and the attending physician, a team from the Group was organized to conduct post-accident radiation measurements at the facility. NIST personnel designed dosimetry to recreate the exposure conditions according to personal accounts. This "simulation" utilized NIST-developed radiochromic dye film and alanine dosimeters. The results were used by the physician to assess the degree of the exposure. In follow-up studies, bone samples from the victim were examined by EPR to measure directly the absorbed radiation dose received by the victim. The details of the NIST and State of Maryland measurements will assist the health physics community in designing improved safety procedures to prevent future accidents, and in formulating measurement protocols for accelerator accident victims. (B.M. Coursey, D.A. Schauer, C.E. Dick, W.L. McLaughlin, J.M. Puhl, and M.F. Desrosiers)

■ **Radiation Accident Dosimetry.** Radiation-induced EPR signals produced in tooth enamel are being studied to retrospectively assess the absorbed dose to people exposed at the Chernobyl reactor accident. Under laboratory conditions, EPR signals have been measured in enamel irradiated as low as a few cGy. Furthermore, it has been determined that the EPR response is independent of photon energy (X or gamma rays). Environmental dose reconstruction will be attempted by measuring radiation-induced EPR signals in mollusc shells in surrounding river and lake beds. Laboratory measurements indicate that the sensitivity of shell may be comparable to tooth enamel. These basic measurements serve as fundamental studies important to future collaborative efforts with scientific institutions in the former Soviet Union. (M.F. Desrosiers and F.G. Le)

■ **Radiopharmaceutical Dose Assessment.** Electron paramagnetic resonance (EPR) spectrometry is being developed as an experimental method of estimating the absorbed dose to bone from internally-administered radiopharmaceuticals. In cooperation with researchers from the University of California, Davis, a humerus from a beagle treated with ^{166}Ho for bone-marrow ablation was examined by EPR. Approximately 40% of the bone has been dose mapped. Preliminary results indicate that the bone dose was dependent on the location of the sample. The dose was found to be greater for trabecular (end) than cortical (midshaft) bone. Also, along the length of the bone, "hotspots" or regions with a significantly higher dose than the adjoining bone, were found. (M.F. Desrosiers, F.G. Le, P. Fattibene, D.A. Schauer, and B.M. Coursey)

■ **Neutron Energy Deposition in Nanometer Volumes.** We have successfully combined the synthesis of Monte-Carlo results for proton tracks of Wilson, Metting, and Paretzke into our analytic method neutron code to calculate neutron energy depositions in site diameters from 2 nm to 1 μm for neutrons in the energy range 1.05 MeV to 15.5 MeV. This development greatly extends the range of the calculations which were previously limited to site diameters of about 0.5 μm and higher. The results are used in modern biophysical models of neutron biological effectiveness which frequently consider both the micron-size volumes (cell nucleus scale) and nanometer volumes (the scale of DNA). (R.S. Caswell and S.M. Seltzer)

■ **Energy Deposition and Radiation Quality of Radon and Radon Daughters.** A computer code derived from the "analytic method" code for neutrons has been used to model the interaction of alpha particles deposited along the rat bronchiole airway by radon daughters ^{214}Po and ^{218}Po. Calculations are run according to various input parameters such as target cell depth (generally 5-15 μm), diameter of the lung airway (from ca. 0.25 to 0.020 cm), and mucus layer thickness. Results are also dependent on the penetration ability (stopping power and energy) of the specific alpha particle. A collaboration is underway with Prof. Werner Hofmann (University of Salzburg, Austria) to apply the results of these calculations to biological models and to suggest the biological consequences of radon and alpha particle exposure. (L.R. Karam and R.S. Caswell)

Neutron Interactions and Dosimetry

■ **Neutron Spectrometer Calibration.** NIST has unique capabilities to provide a variety of well characterized neutron fields for instrument testing and calibration. This capability was called upon to test a new neutron spectrometer being considered by the Defense Nuclear Agency (DNA) and its contractors. The spectrometer consists of four spherical hydrogenous proportional counters designed to cover the neutron energy range from ~80 keV to 4.5 MeV. Absolute neutron intensities vs. energy were measured for pure californium fission neutrons, and for californium neutrons moderated by iron, by water, and by heavy water. The absolute spectrum measurements agreed well with calculation even at the lower energies, an unusual feat for a self-contained integrating neutron spectrometer. Integral parameters, fluence, dose, and dose equivalent, were also checked. Restricting these quantities to within the designed energy range of 80 keV to 4.5 MeV, the agreement between measured and calculated values is ±2 percent, a quite unexpected result. (R. Schwartz and C. Eisenhauer)

■ **Determination of Corrections for Instrument Calibration.** The main problem in accurate calibration of neutron-measuring instruments (Bonner spheres, neutron survey instruments, etc.) is the determination of the corrections for neutrons scattered from the walls, floor, and ceiling of the calibration room. A secondary problem is the deviation from the $1/r^2$ law due to the finite sizes of the instrument and the source. While it is, in principle, possible to work all this out by Monte Carlo calculation, our goal was to try and understand the physics involved and to develop more-or-less simple correction factors. Improvement on a first-order solution to the problem was developed by C. Eisenhauer, in a paper published in 1992. The room scatter correction, based on an analytic model, indicates that the required parameters can be derived *a priori* from the geometry of the NIST calibration room. (C. Eisenhauer and R. Schwartz)

■ **Neutron Transport Calculations for Iron Shell Transmission.** The iron inelastic cross section is important for calculating fast neutron gradients in thick steel and has become a critical issue for predicting the useful service life of power reactor pressure vessels. It was found last year that published reaction rates for threshold detectors with nearly the same threshold diverged as the thickness of an iron slab was increased. We have since established that the published data set for one of the cross sections was in error. (C. Eisenhauer)

■ **The Materials Dosimetry Reference Facility (MDRF).** The high-intensity reference neutron field for reactor dosimetry is in early stages of operation at the Ford Nuclear Reactor (FNR) at the University of Michigan. Designed and constructed by the National Institute of Standards and Technology, the facility will host calibration and validation experiments in support of materials neutron dosimetry for the nuclear power industry and for the metallurgical community engaged in estimating radiation damage in steel. This benchmark is a natural extension of a long-term NIST program to develop standard and reference neutron fields for measurement assurance applications and for testing new detectors and techniques. Field characterization and user operation of the facility is a joint effort by NIST and the Phoenix Memorial Laboratory of the University of Michigan.

Two spectrum options are available to investigate detector response characteristics and to validate the interpretation of dosimetry measurements. Neutron spectra for the two MDRF options are known from two-dimensional DORT calculations with a homogeneous model of the reactor core. The spectra are indistinguishable above 1 MeV and quite similar to the ^{235}U fission neutron spectrum. Below the prominent iron transmission window at 25 keV, the MDRF relaxes into a near-1/E slowing down distribution while the MDRFw/B10 cuts off sharply. Certified neutron fluences for measurement assurance irradiations are established on the basis of neutron fluence transfer from the NIST ^{252}Cf Fission Neutron Irradiation Facility. Spectral indexes for threshold reactions agree well with existing calculations for the lowest threshold detector, but exceed calculations by an average of 12 percent for the higher energy threshold reactions. Low energy detectors are in surprisingly good agreement with the simplified calculational model. (J. Grundl and E.D. McGarry)

■ **Isotopic Mass Standards Development.** Well-characterized isotopic mass standards are frequently required for measurement of neutron-radiation in radiation protection, regulation of the nuclear power industry, and basic research. We are making major efforts to acquire new high quality isotopic deposits and to improve our alpha assay capability for characterization of these deposits. A new set of ^{10}B deposits of unprecedented quality were manufactured by the Central Bureau of Nuclear Measurements (CBNM) in Geel, Belgium this year, in collaboration with our group. A new ^{10}B pulsed ionization chamber of NIST design and manufacture is being employed as a beam monitor in the neutron reaction rate intercomparisons of the new deposits at the at the BR1 Reactor in Mol, Belgium.

The NIST Fissionable Isotope Mass Standards collection is being expanded to serve as a national repository for well-characterized fissionable deposits from other laboratories where program reductions are threatening the loss of valuable experimental artifact standards and archives. In addition, the accuracy of the alpha particle assay capability of our group have been significantly improved. (D. Gilliam)

■ **Search For Time Reversal Violation in Neutron Beta Decay.** A new experiment aimed at improving our knowledge of the fundamental symmetries of nature underwent its first tests at the NG6 beam position at the NIST Cold Neutron Research Facility during 1992. This measurement involves the detection of a three-fold correlation between the angular momentum of a decaying neutron and the direction in which the decay particles (proton and electron) are emitted. The existence of such a correlation would imply a failure of a fundamental symmetry known as "Time Reversal Invariance." Work on this project included a "proof of principle" test which demonstrated the practicality of our novel decay detection system. Collaborators on this experiment are Los Alamos National Laboratory, Harvard University, The University of Michigan, and the University of California (Berkeley). (G. Greene, S. Dewey, and M. Snow)

■ **Gravitational Deformation of Perfect Crystal Interferometers.** An x-ray interferometry experiment, carried out in collaboration with the University of Missouri, measured the effect of elastic deformation of a single silicon crystal. This experiment investigated the possibility of systematic errors in an earlier series of experiments carried out at the University of Missouri Research Reactor (MURR) to measure the gravity induced phase shift of a neutron wave. Systematic errors may result from improper estimation of non-uniform deformation of the crystal within the area which a neutron beam illuminates. Preliminary results indicates the presence of such deformation under the influence of gravity. (G. Greene, M. Arif, and S. Dewey)

■ **Determination of Neutron Lifetime.** A precise value for the free neutron lifetime is important for theorists attempting to unify the strong, electromagnetic, and weak interactions. During the past year a reconstructed neutron lifetime apparatus was installed at the end of beamline NG6. By the end of the year, all of the major subsystems except the proton trapping electronics had been tested and debugged. Among the most significant alterations are a newly designed trap assembly, the ability to raster the decay-proton and neutron detectors, and a new magnet featuring a more uniform magnetic field in the decay region. The proton detector now operates at a lower temperature than previously and the entire apparatus operates safely with higher electric fields than previously. This expansion of usable configuration space increases the precision with which systematic effects can be measured. (S. Dewey, G. Greene, and M. Snow)

■ **Absolute Determination of Neutron Flux.** Extensive development work on two totally-absorbing neutron flux detectors was performed in 1992. The goal is to reach 0.1 percent precision in cold neutron flux measurement. One detector involves neutron calorimetry with a ^{6}Li target and the other uses prompt gamma counting with a ^{10}B target. Preliminary comparison measurements indicate that the detectors disagree despite the success of a number of internal consistency checks. Possible causes for the discrepancy include neutron backscattering, unknown heat loss mechanisms in the calorimeter, and gamma-ray attenuation. Many of these possibilities will be addressed on a monochromatic beam which has been established at the neutron interferometer beam position. The velocity distribution of this beam has been measured with high accuracy in preparation for the calibration of the beam monitor for the neutron lifetime experiment by the totally absorbing detectors. This work is a collaboration between NIST, Harvard University, the University of Michigan and Los Alamos National Laboratory. (D. Gilliam, M. Snow, M. Arif, S. Dewey, and G. Greene)

■ **Establishment of Neutron Interferometry Facility at the CNRF.** A monochromatic neutron beam for NG-7 has been established. The system consists of a parallel tracking dual crystal monochromator assembly. This is the first and only neutron monochromator design which allows a crystal to be manipulated inside a neutron guide remotely and does not require any discontinuity in the guide itself. A milestone in the development of NIST neutron interferometry program was reached when for the first time a neutron beam with nominal energy of 14.8 meV was extracted from NG-7 in May 1992. The initial flux was measured to be 1.1E6 n cm^{-2} s^{-1}. With the present setup with pyrolytic graphite crystals, the monochromator system will provide neutrons with an energy range of 4 meV to 17 meV. Major components of the acoustic isolation system and the primary stage of the vibration isolation system have been installed. A primary collaborator in this project is the University of Missouri-Columbia. (M. Arif, G. Greene, and S. Dewey)

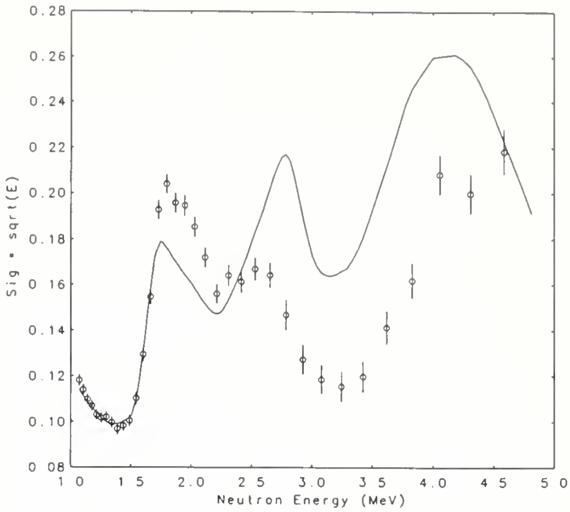


Figure 2 – Comparison of experimental results and ENDF/B-VI evaluation (solid curve). The experimental data are shown with one standard deviation error bars.

▪ **Neutron Reaction Cross Section Measurements.** Improvement in the accuracy of the neutron reaction cross section for ^{10}B is one of the most important nuclear data needs for neutron energies below 10 MeV. We have initiated new collaborative measurements of the total cross section in the 0.1 to 30 MeV neutron energy region using the Oak Ridge Electron Linear Accelerator (ORELA) pulsed neutron facility. Since the accuracy of the measurements is limited by the properties of the boron samples, extensive characterization of the boron is being done at NIST and the Central Bureau for Nuclear Measurements in Belgium. We have also continued the measurements to extend the gamma-ray production cross section to lower neutron energies for normalization purposes. An international interlaboratory working group endorsed by the Nuclear Energy Agency Nuclear Science Committee, chaired by A.D. Carlson, coordinates the efforts to improve this important basic nuclear data standard. The results of our previous measurements of the $^{10}B(n,\alpha\gamma)$ reaction in the 0.2 to 4 MeV neutron energy region have been accepted for publication in Nuclear Science and Engineering. The significant improvements are shown in Fig. 2. (R. Schrack, O. Wasson, and A. Carlson)

▪ **Fission Cross Section Data.** High accuracy measurements have been completed of the neutron fission cross sections for the target nuclides ^{233}U, ^{236}U, ^{238}U, ^{237}Np, and ^{239}Pu which are important for international nuclear data needs. This work covered the energy range from thermal to about 1 MeV neutron energy where difficulties with fission dosimetry standard cross sections existed. These data were obtained at the Los Alamos Neutron Scattering Center (LANSCE) after completion of a major design and implementation of a new flight path during 1992. The large amount of experimental data obtained from this investigation are now being analyzed using the accurately known $^{235}U(n,f)$ and $^{10}B(n,\alpha)$ neutron cross section standards for normalization. Preliminary analysis indicates that these fission cross section measurements will resolve discrepancies and inconsistencies in the existing data bases. (A. Carlson)

▪ **Interlaboratory Measurements of Charged-Particle Production.** The neutron-induced charged-particle production cross sections for oxygen and nitrogen are important for the determination of kerma factors for medical therapy, radiation protection, and space shielding in addition to neutron source calibrations in manganese sulfate baths. Collaborative measurements on oxygen in the neutron energy region from 2 to 40 MeV continued using a neutron time-of-flight beamline at the Los Alamos National Laboratory. During 1992 additional CsI scintillators were incorporated to optimize the system for proton detection. Alpha-particle detection optimization was used during the preliminary studies in 1991. Measurements of neutron energy, along with particle type and energy at four angles were completed during 1992. The analysis of the substantial data collection is in progress while plans for the acquisition of a nitrogen sample for the 1993 measurement season are underway. (O. Wasson and A. Carlson)

Radioactivity Group

■ Dissemination of National Standards of Radionuclide Activity. Continuing primary functions of the Radioactivity Group are the supplying of special SRMs anchored on the national standards and the checking of measurement traceability of subsidiary organizations. Over 700 SRMs were distributed in the past fiscal year, and over 220 certificates of traceability were issued to federal regulatory agencies, radiopharmaceutical manufacturers, commercial suppliers of calibration sources and services, and the nuclear-power industry. Industrial steering committees guided the work of two research associates in cooperative testing programs. The photon spectrum of a popular standard used for the calibration of Ge spectrometers is shown in Fig. 3. (J.M.R. Hutchinson, J.M. Calhoun, L.L. Lucas, and F.J. Schima)

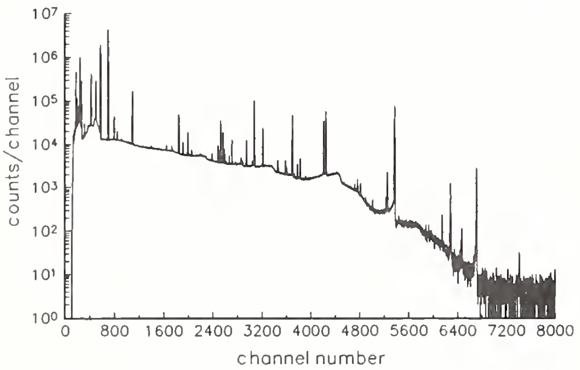


Figure 3 – Spectrum of a "long-lived" mixed radionuclide standard sample.

■ Improved Decay Scheme for ^{144}Ce. The decay scheme of ^{144}Ce was studied to determine the gamma-ray emission probabilities in order to improve the accuracy of germanium detector calibrations. This was done under the auspices of the International Atomic Energy Agency Coordinated Research Program on Decay Data for Detector Calibration and the ICRM Decay Data Workshop. Measurements of gamma-ray abundances were performed in 1992. Three Ge gamma-ray detectors were used and all measurements were averaged to give typical uncertainties of 0.5 percent at one sigma. These results were reported to the ICRM Decay Data Evaluation Workshop of October 1992. (F.J. Schima)

■ Radon Measurements Standards Program. The primary objectives of this program are to maintain the national standards for ^{226}Ra and ^{222}Rn, to develop new transfer standards and measurement applications, and to disseminate standards and provide other mechanisms for insuring the quality of radon measurements. Some highlights of this year's accomplishments include: (1) Three new series of ^{226}Ra solution SRMs, the primary transfer standards for radon emanation, were issued. (2) An interagency agreement with EPA was initiated in which NIST on a routine, continuing basis will provide proficiency/traceability testing of the two EPA laboratories that conduct the national radon measurement proficiency testing program for commercial radon measurement vendors. (3) The extensive data analysis and results for the international marine-atmospheric ^{222}Rn measurement intercomparison conducted last year in Bermuda were completed. (4) Performance testing and final calibrations of the new encapsulated-^{226}Ra/^{222}Rn-emanation standards were completed. The capsules, calibrated against the NIST primary radon measurement system, will be available as new SRMs in 1993. The first field-measurement applications test of the new emanation capsules was also completed. The utility and efficiency of using the capsules to directly calibrate electret monitors for integral radon measurements was demonstrated. This collaboration is being developed into a formalized cooperative research and development agreement (CRADA). (R. Collé, J.M.R. Hutchinson, P.A. Hodge, J.T. Cessna, and M.P. Unterweger)

■ Odd-Even Biasing in Resonance Ionization Spectrometry. The ultrasensitive technique of resonance ionization mass spectrometry (RIMS) is being studied as a means for environmental radionuclide assay of soils, sediments etc. In order to perform such measurements, the isotope dilution technique must be used and it has been the objective of a study to assess the effectiveness of this method. In previous years, we reported an odd-even biasing in the RIMS technique which would seriously affect the accuracy of the method. Theoretical examination of the effect explained the observed discrepancies and further predicted a dependence of this effect with laser intensity. Measurements were performed this year at NIST which corroborated this prediction. This result is convincing evidence that the effect is now understood physically and that the resonance ionization method can be applied with significantly improved accuracies to ultrasensitive measurements of trace elements in, for example, biological or environmental samples. (J.M.R. Hutchinson)

FUTURE OPPORTUNITIES

■ **High-Accuracy and High-Resolution X-Ray Spectral Measurements for Mammography.** In collaboration with the Quantum Metrology Division we shall search for x-ray spectral methods to accurately determine kVp for mammography x-ray machines.

■ **Room Temperature Diode Sensors for Gamma Radiation.** Innovative diode sensors of such materials as CdTe and HgI_2 will be studied for applications to environmental field assessments and radiobioassay.

■ **Microdosimetric calculations and measurements.** In the coming year the Division will focus on merging two strong areas of expertise in microdosimetry: calculations and measurements. Calculational models developed for radon and other alpha particles will be used by experimentalists to design model organic systems for benchmark measurements with radiochromic systems and electron paramagnetic resonance.

■ **Absorbed Dose Standards for Radiation Therapy.** National and international standards groups are moving in the direction of primary standards based on absorbed dose to water for high-energy x-rays and for brachytherapy radionuclides used in radiation treatments. NIST will work with the medical physics research community to develop calorimetric and radiochromic dosimetry systems that will lower the uncertainty in delivered dose to patients.

■ **Neutron Interferometry.** Advanced neutron optical techniques are highly appropriate for performing fundamental tests of quantum mechanics, gravity, and special relativity. To exploit the exquisite sensitivity of these techniques of neutron interferometry, advanced methods of vibrational control, fabrication of single-crystal devices and instrument control methods are under development which, incidentally, are of interest in a variety of high technology and biomedical applications.

■ **Advanced Techniques in Materials Dosimetry.** Newer methods of establishing fast neutron exposure of heavy section steel must be developed and evaluated in order to establish safe margins of steel toughness in high-risk nuclear technology applications. The need is underlined by the early shutdown of some first-generation nuclear power plants, a matter largely dominated by the question of embrittlement reactor pressure vessels.

■ **Fundamental Standard Neutron Cross Section.** Improve measurement of the angular distribution of neutron scattering from hydrogen to 1 percent accuracy in the 15 MeV neutron energy region.

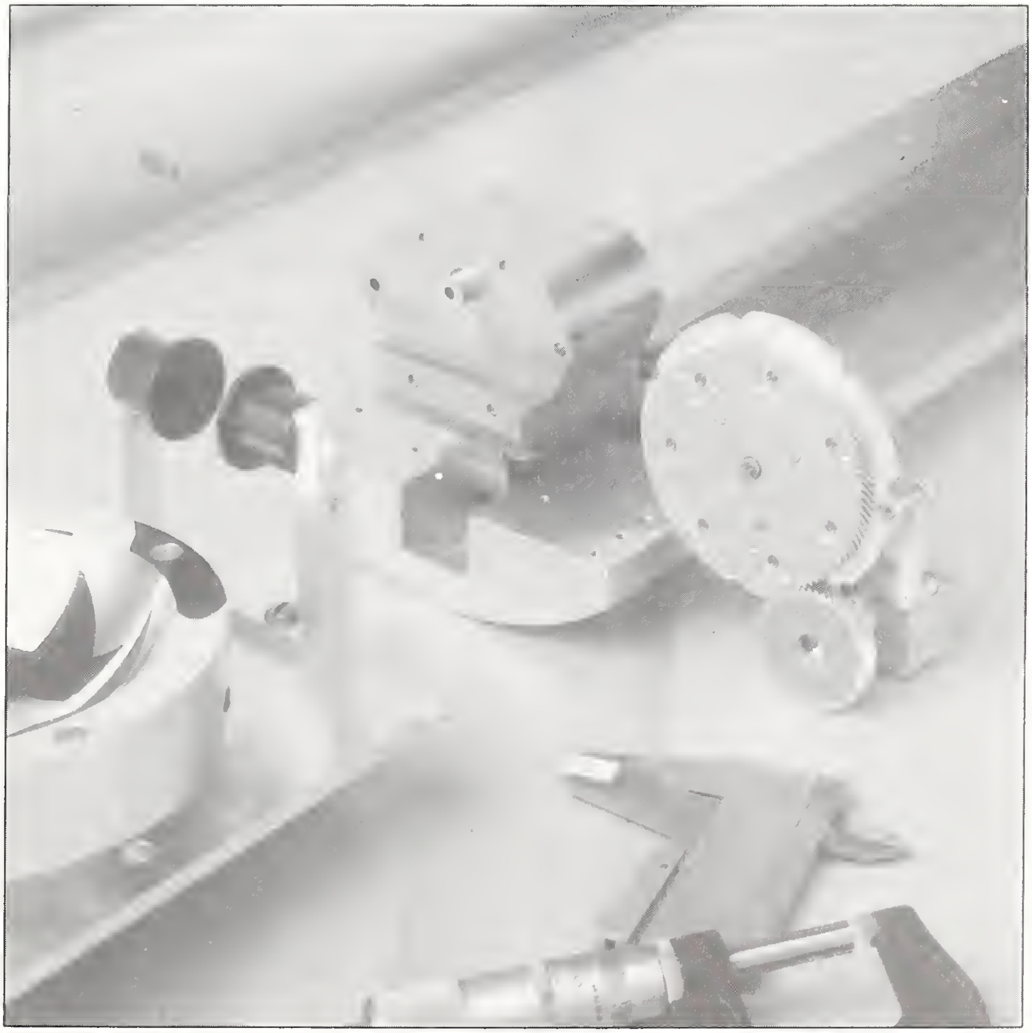
■ **Radionuclides in Industrial Process Control.** The increasing application of radionuclides and radiations in industrial process control will be monitored for possible NIST involvement.

■ **Nuclear Waste Radionuclide Standards.** Standards for very long-lived radionuclides in nuclear waste should be developed. Measuring techniques using selective atom-counting instead of radiation spectrometry may be appropriate if complex chemistry is to be avoided.

■ **Radionuclides in Bioassay**. Programs responding to requirements from documentary standards for NIST involvement in bioassay programs will be initiated. □

TECHNICAL ACTIVITIES

TIME AND FREQUENCY DIVISION



Overleaf

Internal Components of NIST-7. Internal components for NIST's new optically-pumped-cesium frequency standard are shown in the picture. One end of the copper microwave cavity with a small hole for the cesium beam can be seen in the center of the picture. A movable-aperture mechanism for changing the beam collimation is at the right of the cavity. In normal operation this mechanism is placed in front of the cavity. The spherical mirror at the bottom left is part of the light collection optics used in optical-state detection of atoms that have traversed the microwave field. The new standard, called NIST-7, has officially replaced NBS-6 as NIST's primary frequency standard. It currently provides a realization of the definition of the second with an uncertainty of 4 parts in 10^{14}, a factor of two better than the best performance of NBS-6. With more careful evaluation of systematic effects, NIST-7 is expected to achieve an uncertainty of one part in 10^{14}.

TIME AND FREQUENCY DIVISION

MISSION

The mission of the Time and Frequency Division encompasses three primary objectives:

- development and operation of standards of time and frequency and coordination of them with other world standards;
- provision of time and frequency services to the United States; and
- basic and applied research in support of future standards, dissemination services, and measurement methods.

Since length is now derived from the second, the Division has a secondary responsibility for that unit. The primary responsibility for length is in the Precision Engineering Division (MEL).

ORGANIZATION

The Division is organized into eight technical Groups: Ion Storage, Atomic Beam Standards, Phase Noise Measurements, Time & Frequency Services, Time Scale & Coordination, Laser Spectroscopy, Geophysical Measurements, and Optical Frequency Measurements. With a full time staff of 40, the Groups are necessarily small, and the Group Leaders are thus able to function primarily as technical leaders within their areas. The unifying theme of time and frequency technology requires strong interactions (even dependencies) among the Groups. During the last year, the Division hosted 20 long-term guest researchers and 5 postdocs.

CURRENT DIRECTIONS

As a result of the large service component of the Division program, substantial resources are devoted to certain routine operations. These include the operation of the NIST time scale and the primary frequency standards, broadcast of time and frequency signals, and operation of calibration services. Division research and development efforts are undertaken to provide the basis for the future of these operations as described below.

■ **Time and Frequency Broadcast Services.** The Division provides time and frequency broadcasts from stations WWV and WWVB in Fort Collins, Colorado and from WWVH in Hawaii and a time code broadcast from the GOES weather satellites operated by NOAA. The Division also operates a telephone time service, the Automated Computer Time Service (ACTS), designed for setting clocks in digital systems. These broadcasts serve applications in a broad range of systems in business, communications, science, transportation, and computers. Calibration laboratories are served by the Division's Frequency Measurement Service, a system which provides for highly accurate frequency measurements. Work has started on an advanced Satellite Time Service with a projected accuracy over 1000 times better than the current GOES service.

■ **Improved Time Scales.** The NIST Time Scale continues to be the working clock system which provides accurate signals for services and applications and which serves as a reference for research on new standards and measurement methods. The reliability and stability of this time scale is based on the use of an ensemble of commercial cesium-beam standards and hydrogen masers combined together under computer control using a NIST-developed algorithm. The Division is working to improve the performance of the time scale through acquisition of more stable clocks, development of improved algorithms, and improvement of the electronic systems which read the outputs of the clocks.

■ **New Frequency Standard.** The accuracy of the time scale is derived from primary frequency standards which provide the practical realization of the definition of the second. To meet advancing needs the Division has built a new frequency standard, NIST-7, which uses optical pumping methods. This standard replaced NBS-6 on January 1, 1993. The design uncertainty for the new standard is 1×10^{-14}, but the current evaluation is at an uncertainty of 4×10^{-14}. Further work is needed to bring the standard to its full design uncertainty. Looking toward still higher accuracy, the Division is studying trapped, laser-cooled atomic ions as the basis for advanced frequency standards. These offer promise of accuracy improvements of many orders of magnitude. While the ion studies have involved demonstrations of prototype clocks, the work is treated as basic research providing the knowledge base for future development of more accurate standards.

■ **Improved Methods of Time Transfer.** Since the world operates on a unified time system, Coordinated Universal Time (UTC), highly accurate time transfer (to coordinate time internationally) is a critical ingredient in standards operations. The Division has long been a world leader in this field. The Division is working to further improve the NIST-developed, GPS Common-View Time Transfer Method which is the standard for international time coordination. The Division is also continuing efforts to further improve and implement more broadly the Two-Way Time Transfer Method which promises still higher transfer accuracy. A Two-Way link to Europe is being implemented this next year.

■ **Improved Optical Frequency Standards.** The Division is also engaged in developing improved optical sources for use in accurate optical frequency measurements which are important to frequency standards, advanced optical communication, analytical instrumentation, and length measurement. The emphasis in this program is on diode lasers which promise very high spectral purity, simplicity, tunability, and low cost. The approach taken in this work is to prove concepts through demonstration of working systems.

■ **Development of New Phase-Noise Measurements.** The Division's development of new phase-noise measurements supports sound specifications for a range of aerospace systems. Further development work is being undertaken to broaden the spectral coverage and simplify comparison of measurement accuracy between standards laboratories. A new phase-noise calibration service was brought into operation this last year.

■ **Time Synchronization of Telecommunications.** The Division has become strongly engaged with the telecommunications industry in issues relating to distribution of synchronization in advanced generations of telecommunications networks. It appears that the synchronization problems are more severe than designers originally projected, so with the projected expansion of performance expected over the next few decades, the Division will need to expand its efforts in this area.

■ **Applications of Time and Frequency Technology.** Finally, the Division is engaged in the application of time and frequency technology to important problems in high-resolution spectroscopy and geophysics.

TECHNICAL HIGHLIGHTS

■ **NIST-7 Officially Replaces NBS-6 as Primary Frequency Standard.** NIST-7, an optically pumped cesium-beam frequency standard developed by the Time and Frequency Division in Boulder, has officially replaced NBS-6 as the U. S. primary frequency standard. The standard, designed to ultimately operate with an uncertainty of 1×10^{-14}, is already performing at an uncertainty of 4×10^{-14}. The uncertainty budget for this standard is shown in Table 1. At this

Table 1 – Summary of Systematic Uncertainties in NIST-7 (units are 1×10^{-14}) as of the end of 1992.

Effect	Bias	Uncertainty (1 σ)	
		Modeled	Measured
2nd-order Zeeman	≈ 10,000	0.3	1
2nd-order Doppler	≈ 30	0.3	2
Line overlap shift		0.1	—
AC Stark shift	1.9	0.1	1
Cavity phase shift	70	0.3	3
Electronic errors		0.3	1

uncertainty it is two times as accurate as NBS-6 (at the very best performance of NBS-6). Further study of systematic uncertainties will be needed to attain the design uncertainty and additional electronic development is needed to increase automation of its operation.

The development of the standard was led by R. Drullinger, D. Glaze, J. Lowe, and J. Shirley, but they solicited input on the design from many quarters. For example, the design of the microwave system was done in large part by A. DeMarchi of Italy, F. Walls of the Division contributed to design of the electronic systems, and invaluable, overall design review in an early phase of development was provided by L. Cutler of Hewlett-Packard Company.

This is the most accurate optically pumped standard to be used as a primary standard. Previous cesium standards have been based on magnetic-state selection and detection. One key advantage of the technique is greatly enhanced signal-to-noise performance allowing for more rapid evaluation of accuracy. In fact, this standard has the best short-term performance (see Fig. 1) of any cesium-beam standard ever built.

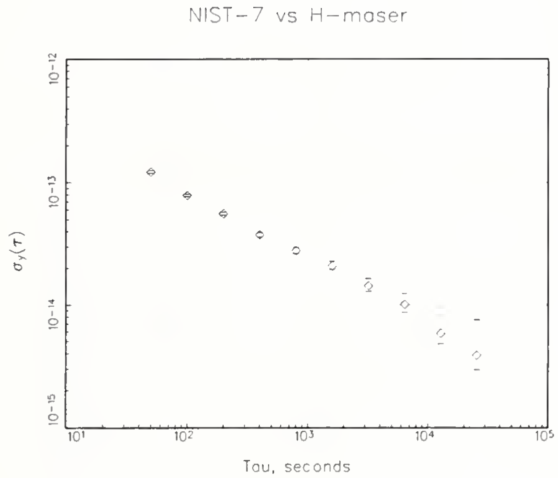


Figure 1 – Short-term stability of NIST-7 as a function of averaging time, Tau. The short-term stability of the hydrogen maser used as reference is sufficiently good that it contributes little uncertainty until the system gets below $\sigma_y(\tau) \approx 10^{-14}$.

When it achieves its full design uncertainty, it will be the most accurate primary frequency standard in the world.

▪ Quantum-Mechanically Correlated States and Atomic Metrology. The Ion Storage Group has recently investigated, theoretically, the possibility of reducing the magnitude of "projection noise" by using two-level systems which are prepared in quantum-mechanically correlated states. In earlier trapped-ion experiments reported last year, they were able to observe this noise which is caused by the quantum fluctuations in the projection process, that is, the fluctuations in whether an atom is projected into either the initial or final state when a measurement is made. This is the fundamental limiting noise in measurements, such as spectroscopic measurements, which detect atomic populations.

They were able to show that certain correlated states can indeed reduce the projection noise substantially, and that it should be possible to experimentally create the correlated states by parametrically coupling the two-level systems to a quantum oscillator. Thus, since some of their measurements have already reached the projection-noise limit, they have a very realistic opportunity to demonstrate this method for beating the "standard" quantum limit. Previous work on reducing quantum limits have focussed on the electromagnetic field. These so-called "squeezed-light" experiments have demonstrated modest improvements beyond the standard quantum limits.

The consequences of this could be dramatic. For example, it has always been thought that the signal-to-noise ratio in spectroscopy should scale as $N^{1/2}$ where N is the number of two-level systems. In ensembles of atoms which are in certain correlated states, the signal-to-noise ratio would scale as N. In an atomic clock using 10^{10} correlated atoms, measurements would yield the same precision in 1 second as an atomic clock using 10^{10} uncorrelated atoms taking 300 years! In principle, the methods can be applied in any situation that detects populations of two-level systems.

▪ Young's Interference Experiment using Two Atoms. The Ion Storage Group in collaboration with Ulli Eichman, a guest researcher from the Universität Freiburg in Germany, have reported the first observation of interference effects in the light scattered from two trapped atoms. The visibility of the fringes can be explained in the framework of Bragg scattering by a harmonic crystal and simple "which path" considerations of the scattered photons. If the light scattered by the atoms is detected in a polarization sensitive way, then it is possible to selectively demonstrate the particle nature or the wave nature of the scattered photons. This is a very vivid demonstration of principles underlying the foundations of quantum mechanics.

The experiments are performed with two trapped $^{198}Hg^+$ ions. The separation of the ions can be adjusted by changing the potential well of the trap. "Which path" a given photon takes in the experiment (that is, which atom scatters the photon) can, in principle, be determined when σ-polarized light is detected, since a photon with this polarization, when scattered, leaves one of the atoms in a different state. Therefore, when σ-polarization light is detected no interference is seen because the experimental conditions present the opportunity to determine the photon path. On the other hand, the detection of π-polarized light involves a transition where the initial state and final state of the atom are identical. There is no way to determine which atom scattered a given photon, and in this case interference is observed as seen in Fig. 2(a).

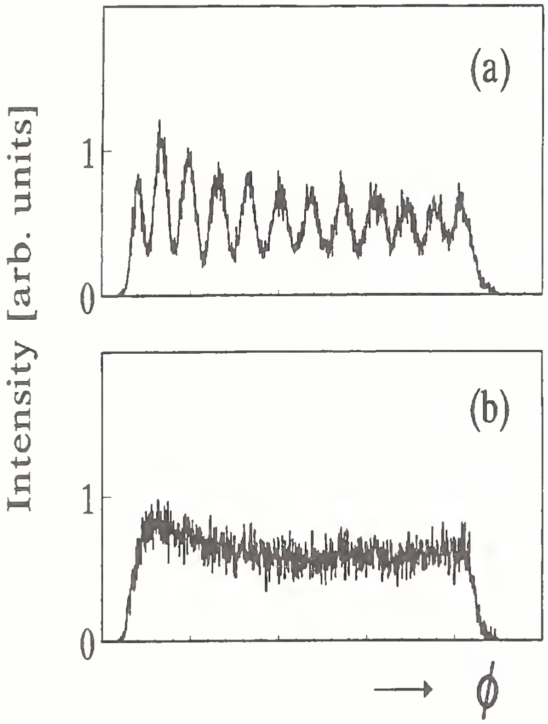


Figure 2. Polarization sensitive detection of the scattered light: (a) π-polarized scattered light, showing interference, (b) σ-polarized light, showing no interference pattern as explained in the text. ϕ is the angle of observation relative to the direction of the incoming light.

■ Feasibility of Laser-Cooled Positron Source. J. Bollinger, C. Weimer, and D. Wineland of the Ion Storage Group have examined theoretically the feasibility of producing a sample of cold, high-density positrons which are contained in a Penning trap. Such trapped positrons may be useful in antihydrogen production (by passing antiprotons through the positrons and relying on antihydrogen production through three-body recombination), as an example of a quantum plasma, and as a possible means to produce a bright beam of positrons by leaking them out along the trap axis.

A schematic of the proposed positron accumulator is shown in Fig. 3. Beryllium ions are first loaded into the trap and laser cooled to form a uniform density column centered on the trap axis. Positrons from a moderator are then injected into the trap along the direction of the magnetic field (axial direction) so that they intersect the beryllium column. Collisions of the positrons with beryllium extract energy from the positrons preventing them from escaping back out the entrance aperture. Cooling provided by cyclotron radiation and sympathetic cooling through interaction with the beryllium ions causes the positrons to eventually coalesce into a cold column along the trap axis with the beryllium ions forming a hollow column which surrounds the positrons. The efficiency for capturing the positrons has been estimated to be close to 100% for a beryllium plasma of 10 cm length. The limiting densities and temperatures of the resulting positron column have also been estimated.

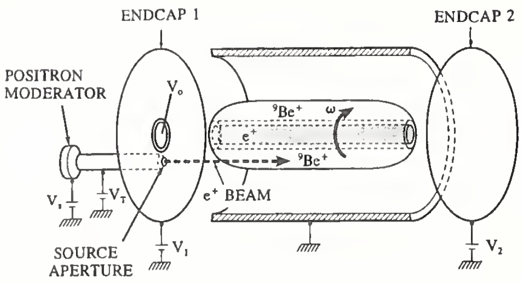


Figure 3 – Schematic diagram of a possible Penning trap system for capturing and cooling positrons injected into the trap from a moderator. A magnetic field is applied parallel to the axis of the electrodes. The beryllium ions damp the motion of the positrons along the magnetic field direction causing them to be trapped. As the positrons are cooled, they are forced inside the beryllium ions where they eventually form a cold column centered on the trap axis.

The validity of the concept is supported by previous experimental work on two-species nonneutral plasmas. These earlier experiments, which used ions with substantially different masses, clearly demonstrated the spatial separation of the species and sympathetic cooling of one species by another.

■ Mode Frequencies in Ion Trap Plasmas Determined. J. Bollinger, W. Itano and D. Wineland of the Ion Storage Group along with D. Heinzen and F. Moore of the University of Texas and D. Dubin of the University of California at San Diego have calculated and measured the electrostatic modes for certain classes of ion trap plasmas. Experimental measurements of the mode frequencies on laser-cooled, beryllium-ion plasmas in a Penning trap showed good agreement with the calculations. Detection of these modes provides a nondestructive method for obtaining information on the plasma density and shape. This is important in many trapped-ion experiments where direct visual information, by laser scattering, is not available. In addition, excitation of these modes may provide a practical limit to the density and number of charged particles that can be stored in a Penning trap. An example of a comparison between experiment and theory (no adjustable parameters) for one particular mode is shown in Fig. 4.

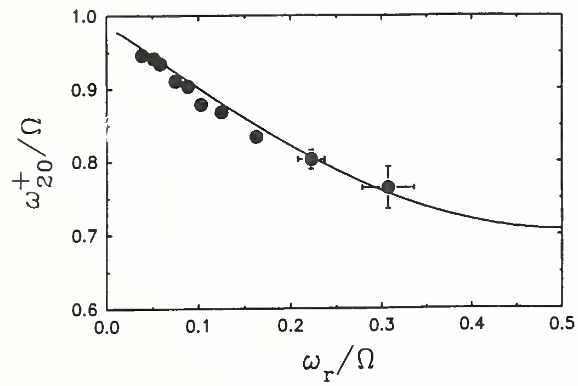


Figure 4 – "Upper hybrid-mode" frequency ω^+_{20} as a function of the rotation frequency ω_r for ω_z/Ω = 0.151 where ω_z is the trap axial frequency. Frequencies are expressed in units of the cyclotron frequency Ω. The solid line is the prediction of the theory. The uncertainty for measurements done at lower rotation frequencies is approximately the size of the circles. At high rotation frequencies the uncertainties increase because the mode becomes difficult to excite.

■ **High-Order Multipole Excitation of a Bound Electron.** C. Weimer, F. Moore, and D. Wineland of the Ion Storage Group have observed a number of degenerate and non-degenerate parametric processes in the limit where multipole interactions dominate the nonlinear interaction between bound electrons and electromagnetic fields. Nonlinear processes such as harmonic generation normally dominate because they involve electric dipole transitions which have much larger moments. The Group used a single bound electron in a Penning trap to demonstrate these processes. This system can be thought of as a pseudo atom. Among their various observations were a subharmonic response to third order of the cyclotron frequency (3.08 MHz for their system), a subharmonic response as high as ninth order of the magnetron-motion frequency (615 kHz), and stimulated Raman excitation of the cyclotron motion. The subharmonic response, acting as a frequency divider, could eventually prove useful for measurement of optical frequencies and for optical frequency synthesis. By improving the magnetic field stability it should be possible to observe much higher order nonlinear response.

■ **Flicker Noise in Quartz Resonators.** F. Walls of the Time and Frequency Division in collaboration with P. Handel of the University of Missouri have developed a new theory for flicker noise in quartz resonators. This is the type of noise that normally limits the performance of high quality quartz oscillators. The most interesting prediction of the theory is a dependence of the magnitude of the flicker noise on the volume of the quartz crystal lying under the exciting electrodes. A careful analysis of the performances of many different types of quartz resonators confirms the dependence on volume. This work has stimulated the design of a number of new quartz resonators with smaller active volumes with the expectation that the flicker noise floor of quartz oscillators will be reduced by 5 to 10 dB. Such improvement could have substantial impact on the short term performance of atomic standards that use quartz as local oscillators. Success could also have impact on a wide range of instrumentation (for example, frequency counters).

■ **Frequency Stability Measurements for Short Time Intervals.** F. Walls of the Time and Frequency Division has developed and demonstrated a new algorithm for computing fractional frequency stability of frequency standards that reduces the noise in measurement systems by about two orders of magnitude over measurement times from 0.5 to 10 seconds as shown in Fig. 5. This data processing algorithm relies on the use of two similar channels measuring the difference in performance of the two oscillators (one reference oscillator and one oscillator under test). A cross correlation of the data acquired through the two measurement channels permits a faster assessment of the measurement system noise yielding a better assessment of the short term stability. This is critical for characterization of performance of the next generation of frequency standards. The new algorithm will also reduce noise in time transfer through links such as GPS. This measurement system noise properly averages out in the long term, and so does not affect the results in the longer term.

■ **Measurement of Amplitude Noise in Electronic Systems.** Amplitude modulation (AM) noise

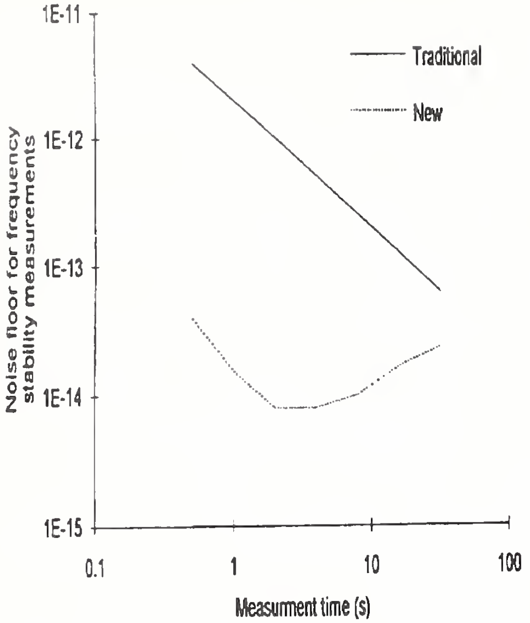


Figure 5 – Comparison of noise floors (fractional-frequency) using traditional methods and the new cross-correlation method.

often limits the performance of oscillators and complex measurement systems. Present commercial AM detectors have noise floors that are well above the AM noise in high performance oscillators and some other measurement systems. To circumvent this difficulty F. Walls of the Time and Frequency Division has developed a two-channel, cross-correlation method for reducing the measurement noise (relative to the best commercial detectors) by about 20 dB. This new approach to measuring AM noise will, for example, permit the study of the relationship between AM and PM (phase modulation) noise in high performance oscillators. There are no models for AM noise in oscillators, but there has been some speculation that nonlinear effects can produce a coupling between PM and AM noise. Such coupling could convert PM noise to AM noise.

■ **New Spectral Observations with Enhanced LMR Sensitivity.** K. Evenson of the Time and Frequency Division in Boulder along with J. Brown, a Guest Researcher on sabbatical leave from Oxford University, have recently observed a number of "new" spectra of atomic and molecular species using a substantially improved laser magnetic resonance (LMR) spectrometer. LMR spectroscopy was invented in the late 1960's in Boulder and there are now a number of LMR spectrometers in operation throughout the world. All of these systems have produced a steady stream of results, but the NIST enhancements of LMR sensitivity have resulted in a rapid succession of new observations. New atomic spectra include ^{17}O in natural abundance, ^{16}O sub Doppler, S, Si, Fe, and Al. A new discharge source has permitted a large increase in the detectability of ions. Observations include the ^3P fine structure transitions in N^+, the $X^3\Sigma$ ground state and $^1\Delta$ metastable states of OH^+, and NH^+. The results represent a major advance in spectroscopy with potential applications in studies of important species in space and in the upper atmosphere.

The three instrumental improvements providing for these new results were: an increase of the magnetic field modulation frequency from 13 to 40 kHz, an improvement in the laser pump efficiency at short wavelengths, and the addition of a new intra-laser-cavity microwave discharge to the sample region. The higher modulation frequency increases the instrumental sensitivity three-fold; higher pump efficiency permits 3 to 4 times more laser lines to oscillate in the 40 to 100 μm region, and the new microwave discharge cavity permits the formation of ions within the NIST far infrared LMR spectrometer for the first time.

The observation of ^{17}O in natural abundance as shown in Fig. 6 provides a vivid demonstration of the LMR enhancements. This figure shows the ^{17}O spectrum along with a single line

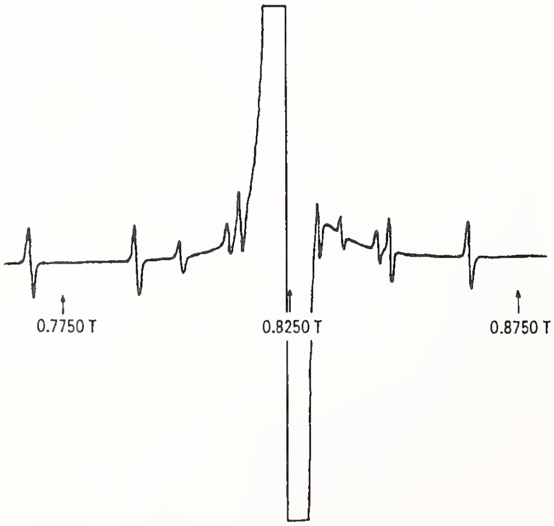


Figure 6. Laser-magnetic-resonance spectrum of ^{17}O and ^{16}O at 4.753785 THz. The horizontal axis is linear in magnetic field with the calibration points shown. The central feature that goes off scale is due to ^{16}O. A gain reduction of more than 10^4 is needed to bring it to an amplitude comparable to that of the ^{17}O lines.

of ^{16}O using a far infrared laser oscillating at 63.1 μm (4.75 THz). The ^{16}O line, first observed by Saykally and Evenson in 1979, goes off scale; a gain decrease of 10^4 is needed to bring it back on scale. This dramatically different scale is due primarily to the low natural abundance (0.034%) of ^{17}O, but the splitting of the ^{17}O line into 12 hyperfine components also makes the lines an additional order of magnitude smaller than the large ^{16}O line.

■ **Spectroscopy of Cooled Neutral Atoms.** High-resolution optical probing of excited states of cold trapped atoms has been demonstrated by L. Hollberg, R. Fox and J. Marquardt of the Time and Frequency Division in collaboration with S. Gilbert of the Electromagnetic Technology Division (EEEL) and H. Robinson of Duke University. While the potential for high-resolution work with slowed and trapped neutral atoms has been well recognized, very little high-resolution optical work has been done with them. This is in sharp contrast to impressive demonstrations of extremely high resolution optical spectroscopy with laser-cooled, trapped ions.

The current work has involved rubidium and cesium atoms trapped in magneto-optic cell traps using diode lasers tuned to resonance lines. Additional lasers were used to probe excited states of the cooling transition with very high resolution. These excited-state transitions are the ones of immediate interest in this work. The cesium experiments using an excited-state transition at 658 nm are being undertaken in the Time and Frequency Division to develop a better understanding of the concepts so that they might ultimately be applied to optical frequency and length standards. Cesium is chosen for the studies because diode lasers match the cesium transitions, cesium is important for future microwave frequency standards, and cesium is fairly easy to handle. One particular application of great interest is the development of a length standard based on a calcium transition at 657 nm.

The rubidium experiments undertaken in the Electromagnetic Technology Division are aimed at providing wavelength (frequency) standards in the optical communications bands near 1 μm. In this case rubidium is chosen because it has excited-state transitions at frequencies within the optical communication bands. A fiber laser is used to excite these transitions.

■ **Laser-Enhanced-Ionization Spectroscopy.** R. Fox and L. Hollberg of the Optical Frequency Measurements Group in collaboration with G. Turk of the Inorganic Analytical Research Division (CSTL) have used diode lasers to detect trace impurities by two methods, direct absorption and laser enhanced ionization in flames. In one experiment they demonstrated a detection sensitivity of 300 ppt (parts/trillion) of rubidium in water. Their first experiments have been performed on rubidium and cesium since the lines for these could be easily reached with readily available diode lasers.

The very simple experimental system consisted of an atmospheric-pressure, air-hydrogen (or acetylene) flame and water samples that contained the atoms of interest at low concentrations. The water samples were aspirated into the flame where the diode laser excited the atoms which were ionized by the flame and the electric field from a high voltage electrode. Example experimental data for rubidium are shown below in Fig. 7.

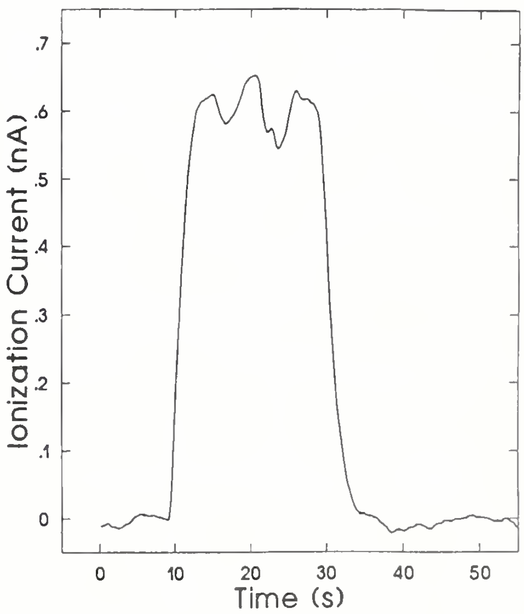


Figure 7. 10 ppb rubidium in water detected with a diode laser using laser-enhanced ionization in a flame.

The results demonstrate a clear promise for diode lasers in analytical chemistry. There are many other optical methods that would be applied in chemical analysis if the lasers were not prohibitively cumbersome and expensive. The simplicity, low cost and small size of the diode lasers make them attractive for such analytical applications. However, in some cases it will be important to reduce the natural linewidth, and it is important to extend the frequency coverage, particularly to the blue/green region where many important chemical lines are found. Progress on blue light generation, being made in this lab, should expand chemical analysis and other NIST measurement applications of diode lasers.

■ **Optical-Frequency-Difference Measurements Using Schottky Diodes.** S. Waltman and L. Hollberg of the Time and Frequency Division in collaboration with M.P. Sassi of Torino, Italy have used Schottky diodes as mixers to demonstrate measurement of optical frequency differences greater than 400 GHz. The method should prove useful in the measurement of optical frequencies relative to a locked optical-frequency reference or as means for scanning a laser frequency that is accurately known relative to a reference.

In the present experiments, the radiation from two slightly offset 830 nm diode lasers are sent to a very-small-area Schottky diode that generates a difference (beat) frequency. At 25 GHz the signal-to-noise ratio for the beat signal is ~60 dB (with a resolution bandwidth of 10 kHz). The Schottky diode was also used as a harmonic mixer to generate harmonics of a 47 GHz signal. The difference-frequency signal between the two-laser-difference signal and harmonics of the 47 GHz then provided a measure of the Schottky-diode frequency response which went to at least 400 GHz. This corresponds to a coherent frequency measurement over 0.1% of the optical frequency. Of course, the amplitude of the harmonics decrease as the harmonic number increases, so this measurement provides a conservative measure of frequency response. With appropriate local oscillators still higher frequency response should be achieved.

■ **Meeting on Frequency Stabilized Lasers.** L. Hollberg of the Time and Frequency Division in Boulder served as cochairman for a meeting on "Frequency Stabilized Lasers and Their Applications" held 15-20 November 1992 in Boston. The International Society for Optical Engineering sponsored this international applications symposium on optics, electro-optics, and lasers in industry. Other co-chairmen were Y.C. Chung of AT&T Bell Laboratories, S. Ezekeil of the Massachusetts Institute of Technology, M. Ohtsu of the Tokyo Institute of Technology in Japan, H.R. Telle of the Physikalisch-Technische Bundesantalt in Germany, and V.V.L Velichansky of the P.N. Lebedev Physical Institute in Russia.

The meeting focussed on frequency stabilized semiconductor lasers, other frequency stabilized lasers, atomic clocks, spectroscopy, lightwave systems applications, optical frequency synthesis, optical frequency measurement techniques and other related applications.

■ **High-Accuracy Geodimeter.** J. Levine of the Time and Frequency Division along with A. Brewer and M. Volk (CU graduate students) have demonstrated exceptionally good precision in intermediate distance measurements using a three-color geodimeter. Typical measurement results along the primary 24-kilometer test baseline running between Boulder and Erie are shown in Figure 8. Such distance measurements

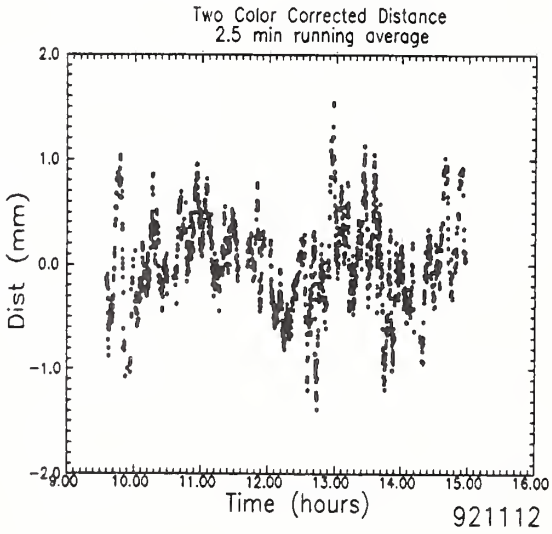


Figure 8. Stability of measurement of the 24 kilometer, Boulder-Erie baseline using only two colors for correction.

through the atmosphere are limited in reproducibility by normal fluctuations in dispersion (index of refraction and thus speed of propagation) of the atmosphere. The scatter in measurements along this fixed baseline is more than two orders of magnitude smaller than it would be using simple time of flight measurements in typical atmospheric conditions. The geodimeter uses measurements at one microwave and two laser frequencies to determine the dispersion along the path and then correct for it. The microwave measurements provide information related to water-vapor content along the path. Since Boulder is so dry, this measurement is not always needed.

The initial phases of the work emphasized stability, but more recent efforts have been devoted to establishing the accuracy of the method. A comparison with GPS measurements of the same baseline is being considered. Planning is also under way for a series of tests in the San Francisco Bay region of Northern California. These tests will involve study of long term changes in baselines extending across the Hayward fault which runs generally north and south along the eastern edge of the Bay. Work on this device has been funded by the U.S. Geological Survey.

■ **Computer Time Service Experiences Large Growth.** The Automated Computer Time Service (ACTS), operated by the Time and Frequency Division, has been experiencing a large growth rate from its inception in 1988. ACTS delivers a digital time/date code which computers can access in an automated way. It provides advanced alert for both the leap second and changes to/from daylight savings time. One option even provides correction for the telephone-line delay. The accuracy of time delivery using this option can be nearly one millisecond. The system and user software for accessing it were developed by R. Davis, M. Weiss, D. Allan, and J. Levine. The NIST user software, marketed through the NIST Standard Reference Material Program, has proven to be a big seller. The service appears to be popular with users because it requires no special hardware, it is easily implemented, and the cost of the short calls needed to set clocks is small. The software is being used, for example, to automate time setting during computer booting, to assure synchronization of computer clocks in business network applications, and to provide legal traceability for time. The need for such a service is heightened by the very poor quality of many computer clocks, particularly those used in personal computers.

Since initiation of the service, the doubling period for the number of calls has been well under a year and the current level of use is better than 4000 calls per day. Growth has been stimulated by the development (by others outside NIST) of additional software that accesses the system. For example, a recent growth spurt was stimulated by the publication in PC Magazine of a windows program for accessing the service. The majority of users are content to live with the error introduced by the line delay (on the order of a few tens of milliseconds), but a modest fraction do use the high-accuracy (delay-correction) option. Three new telephone lines have been added recently bringing the total number of lines to nine. These lines should handle growth to well beyond 10,000 calls per day.

Several additional developments will expand the application of the concept. J. Levine has recently completed development of a server that can supply an ACTS-like time service to computers through INTERNET and he has started development of a secondary-node ACTS system which should more efficiently serve large sites. Such an ACTS node would acquire and keep time through calls to ACTS at NIST, and any other local computer would then acquire time through a call to the local node.

■ **NIST Broadcasts Support INSPIRE Program for Science Students.** NIST time and frequency broadcast station WWV provided short broadcasts of scheduling information to high school science students participating in the Interactive NASA Space Physics Ionosphere Radio Experiment (INSPIRE). This unique program involved radio reception of signals produced by a beam of accelerated electrons modulated at various audio frequencies. The beam of electrons was guided by the earth's magnetic field producing a large virtual antenna. The experiment required reception of the signals on earth with a geographically diverse network of receivers. This network was provided by INSPIRE which is a group made up of physicists, amateur radio enthusiasts, scientific experimenters and teachers. One objective was to involve a large number of high school students in the program.

Equipment for the satellite-signal broadcasts was carried on the space shuttle in March, 1992 in the first of ten ATLAS (ATmospheric Laboratory for Applications and Science) missions. Taped observations made by the INSPIRE network were gathered to determine the footprint of the arriving signals thus providing information on the propagation of signals through the ionosphere and magnetosphere. Since the schedule of broadcasts from space was subject to changes, a means for communicating these changes to the observers was needed. With its broad geographic coverage, the NIST shortwave broadcasts were able to meet this need. Furthermore, automated methods for recording messages for broadcast were already in place providing special announcements (e.g., marine storm warnings) for other agencies. NIST is prepared to support similar experiments in the future.

■ **WWVH in Kauai Survives Hurricane Iniki.** When Hurricane Iniki hit Kauai, Hawaii on September 11, 1992 it did damage to NIST's time broadcast station WWVH, but amazingly the station stayed on the air through and after the storm. When it became apparent that Iniki was going to hit Kauai, Chief Engineer D. Okayama had the station disconnected from commercial electrical power for operation on a backup diesel generator. While the storm blew away part of the roof of the transmitter building and damage was done to antennas, fencing and storage buildings, the main and backup systems of the station performed properly providing for continuous time broadcasts.

After the storm, the station's four-person staff, which includes, besides Okayama, technical staffers D. Patterson and E. Farrow and secretary A. Ochinang, worked 12-hour days through the weekend and following weeks to clean up the site and help repair the damage. Without their efforts, the cost of cleanup would have been dramatically higher than the $40,000 final cost. As for the employees, they and their families all came through the hurricane safely with only minor damage to their homes. Commercial power was not restored to the facility for nearly two months following the storm requiring substantial effort to keep local generators in operation.

■ **Workshop on Telecommunications Synchronization.** The Time and Frequency Division in Boulder has just completed a special, three-day "Workshop on Synchronization Standards for Telecommunications Systems." The workshop, attended by 43 representatives of the industry, was organized by M. Weiss of the Division with speakers from both industry and NIST. A key objective of the event was to familiarize industry representatives with new, NIST-developed measures of system performance that have recently been adopted as standards by both the U.S. industry and the international telecommunications community.

The performance measures developed for specification of phase noise in components of telecommunications systems are variations of the two-sample variance developed by the Division to deal with the non-white noise processes found in clocks, oscillators, and time transfer systems. Traditional statistical measures cannot be applied to such devices. NIST developed the new measures in response to an industry request for assistance. This industry has experienced greater competition since the divestiture of AT&T, but the competing companies recognize the need to cooperate on measurement and standards issues. The development of advanced optical fiber systems by this invigorated industry has resulted in an environment where existing specifications and measures are recognized as inadequate. The response of the industry to NIST work in the field has been very positive suggesting that NIST will remain heavily engaged with the industry for some time to come.

■ **Standardization of International GPS Time Transfer.** Staff of the Time and Frequency Division are playing a key role in standardization of protocols used for international time transfer by the NIST-developed Common-View GPS Method. The method requires exchange of observation data acquired through scheduled measurements by receivers located at the world's major timing centers. Initially, standardization was easily achieved because all sites were using NIST-designed receivers (over 500 receivers currently use the microprocessor core and NIST software), but a more formal standardization is now required for two reasons. The first is that there has been a growing need for additional information involving, for example, actual measurements of ionospheric delay that can be used to reduce delay errors. The second reason is that other receivers are now being used and the differing data formats are beginning to create an unnecessary burden in processing the large volume of data. M. Weiss, Dick Davis, and J. Levine have played key roles in this standards activity which is taking place in a subcommittee operating under the Consultative Committee for the Definition of the Second. Implementation of the final standard in the form of a read-only memory chip for NIST-type receivers will be directed by M. Weiss of NIST. The target date for implementing the new standard is July 1993.

■ **Improved Synchronization for LORAN Navigation System.** The Time and Frequency Division has been funded by the U.S. Coast Guard to assist in improving the synchronization of North American LORAN-C navigation systems to a level of 100 nanoseconds using NIST-developed Common-View GPS Time Transfer. A LORAN-C user determines position using phase measurements of the 100 kHz signal received from several transmitting stations. The level of required synchronization was specified by recently enacted federal legislation. The objective of the improved synchronization is to provide more accurate navigation in situations where aircraft receive signals from different LORAN-C navigation chains. The present system design involves small groupings of stations that are tightly synchronized to a master station in the group.

Heretofore, synchronization between chains has been at a much lower level. Aircraft typically use signals from stations in only one chain and must acquire a new set of stations in a different chain as they fly cross country. Preliminary tests with a single receiver at the Seneca, New York station are in progress. Receivers for the 11 master stations in the contiguous 48 states and Alaska are being procured. Work on this project is being led by R. Davis, J. Levine, and M. Weiss.

FUTURE OPPORTUNITIES

In the course of conducting current programs, the Division has developed capabilities putting it in a unique position to pursue certain programs. While the list of opportunities is far greater than the resources available to pursue them, it is nonetheless worthwhile to examine them here. The special capabilities of the Division include: (1) systems for trapping and cooling ions; (2) highly stable lasers and microwave sources for high resolution studies of atoms and molecules; (3) well-characterized atomic beams; (4) high-resolution systems for imaging atomic particles; (5) low-phase-noise components and systems; (6) satellite-timing receivers and transmitters. The Division also has a strong tradition of accurate frequency measurement across the electromagnetic spectrum and leading-edge talent in statistical analysis of time series of data. Considering these assets, we list the following examples of basic and applied research opportunities.

■ **Atomic Physics.** In atomic physics, Division programs are centered on strengths in ion trapping, cesium beams, low-noise frequency synthesis, and accurate frequency measurements. Example measurements include:

- Measurement of Atomic Decay Times. The previously demonstrated cooling of ions to their quantum ground state of motion should permit atomic decay times of allowed transitions to be determined by measuring the Lorentzian line shapes of the trapped ions. Potential accuracies are better than 10^{-3}.
- Study of Radiation Statistics of Atomic Systems. Here, we observe transitions in systems involving one or a few atoms where cooperative effects and nonclassical statistics such as antibunching and sub-Poissonian statistics can be studied.
- Study of Influence of Radiation Fields on Atoms. Here we can compare predictions of quantum and semi-classical theory and study radiation damping and frequency pulling in cavities (cavity QED).
- Search for Violation of Time-Reversal Invariance. A search in an alkali metal (e.g., cesium) for a static electric dipole moment could provide a really exacting test of this important principle.
- Mass Ratios. The "coupled trap" project currently underway in the Ion Storage Group has the potential to push cyclotron-resonance mass spectroscopy to its natural limit – that is, excite the cyclotron motion from the ion's motional ground state to the first cyclotron quantum level. This will eventually be important in reducing the systematic effects associated with the motional amplitude such as nonlinear effects due to trap imperfections and relativistic effects.
- High-Resolution Optical Probing of Cold, Trapped Neutral Atoms. Such probing is needed to study trapped neutral atoms and it may be useful for future applications.

■ **Molecular Physics.** Spectroscopy is being performed with coherent radiation using tunable far-infrared (TuFIR) and laser magnetic resonance (LMR) systems. Both of these provide for highly accurate and very sensitive measurements of atomic and molecular spectral line frequencies as well as line shapes. Such measurements are important not only as secondary frequency and wavelength standards, but also in atmospheric physics and astrophysical research, areas in which the Division interacts strongly. The Division capability can be used to observe and characterize spectra of unusual and rare molecules, molecular ions and free radicals which heretofore have not been observable in the laboratory. The dependence of line shape (and width) on temperature and pressure, which can also be precisely determined in the laboratory, can contribute to remote sensing of important upper atmospheric molecules. Further development of diode lasers will certainly support all of this work, and will result in unique opportunity for ultrasensitive spectroscopic detection of atoms and molecules providing for practical monitoring of important species.

■ **Optical Physics.** Studies in optical physics revolve around the need to develop very narrow-line sources of radiation at a variety of frequencies (from the microwave to the visible) and to accurately measure optical frequencies. Laser studies, including studies of fundamental noise processes, involve gaseous lasers, dye lasers, solid-state lasers and diode lasers. Particular emphasis is placed on development of stabilized, narrow-linewidth diode lasers which show great promise for a wide range of standards and precision measurement applications. There is also need for further development of mechanical isolation of reference cavities, used recently, for example, in demonstrating the world's most stable dye laser. Long term laser stabilization is best provided by locking to an optical transition in trapped ions or atoms.

The Division is studying standard approaches to measuring optical frequencies involving frequency multiplication. This requires the development of an understanding of mixers such as Schottky diodes, metal-insulator-metal (MIM) diodes, nonlinear crystals, vacuum-tunneling diodes and, perhaps, superconducting (Josephson or quasiparticle) junctions. The Division is also studying frequency division schemes involving diode lasers and nonlinear optical materials. Such division could simplify and improve measurement of optical frequencies.

Laser cooling and Doppler-free spectroscopy are traditionally categorized under optical physics and should be included, since they constitute major components of the Division program.

■ **Plasma Physics.** Stored clouds of beryllium and magnesium ions (which are being studied as frequency standards) constitute very interesting nonneutral plasmas. These plasmas have distribution functions which are closely related to those for neutral plasmas. Under proper laser-cooling conditions, such plasmas become strongly coupled and can be liquid or solid. Important experiments to consider involve study of Bragg scattering, ion diffusion, phase transitions, Coulomb clusters, the classical limit of Wigner crystallization, and multispecies ion plasmas. Such studies are also relevant to the development of frequency standards since a full understanding of the dynamics of ions in these systems provides the basis for estimating systematic errors (primarily Doppler shifts) arising from ion motion.

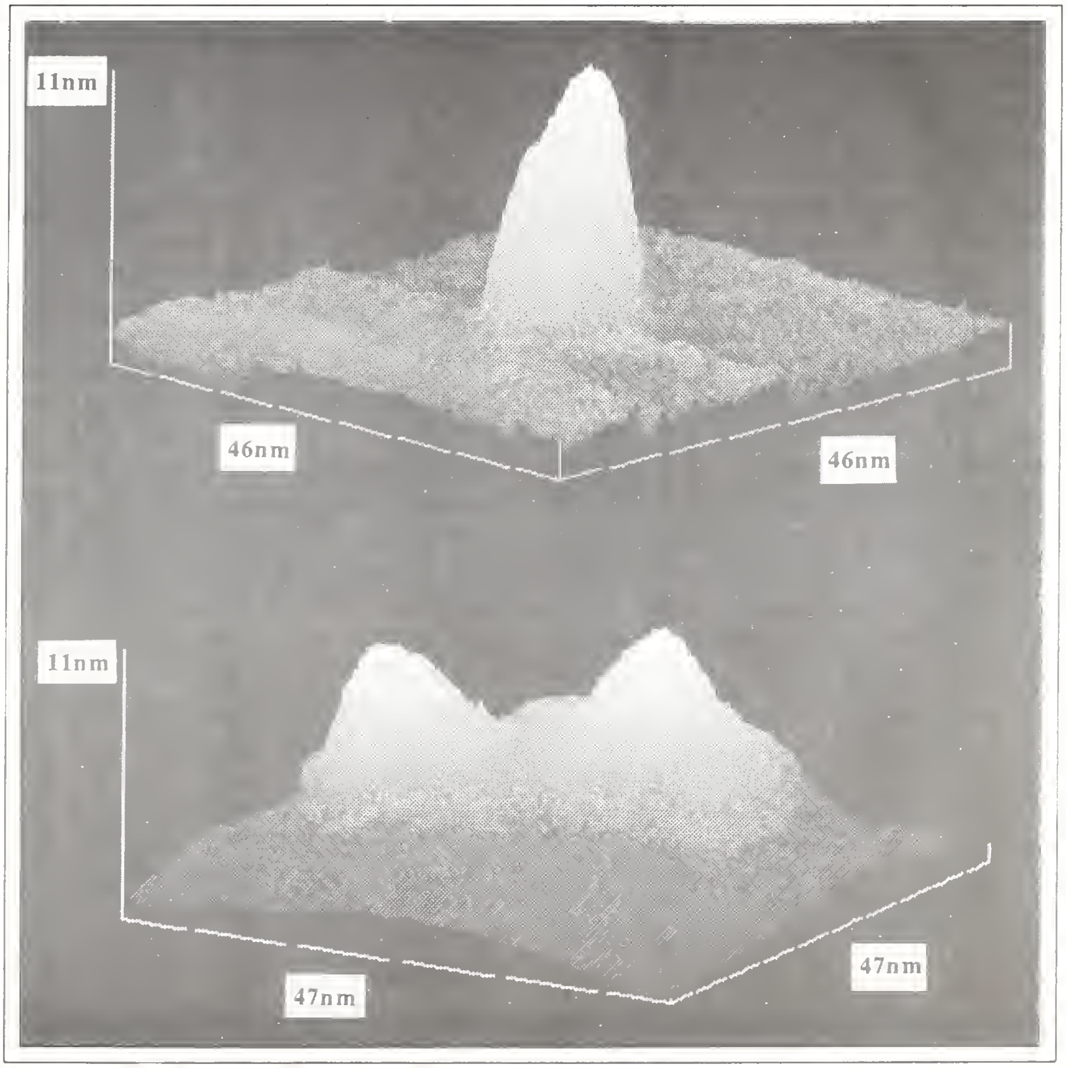
■ **Satellite Timing.** One of the primary limitations to accuracy of satellite time transfer is the uncertainty in signal propagation time which arises from variations in the index of refraction of the troposphere and in the electron density of the ionosphere. Knowing the stability of the reference clocks, one can gain understanding of these delays through the additional uncertainties which they add. Alternately, they can be studied by using several carrier frequencies. The multifrequency method is particularly interesting as it applies to precise geophysical (length) measurements both between ground stations and satellites and between separated ground stations. Another important area for study involves the magnitude and the stability of delays which can be attributed to system hardware or to interfering signals.

■ **Time Series Analysis.** Over the last two decades, the Division has led the development of the statistical analysis of time-series data using the two-sample (Allan) variance. In a preliminary way, these techniques have been applied in other disciplines, e.g., standard volt cells and mechanical gage blocks. It appears that significant insight into the long-term stability of these systems can be gained through these methods. The more common use of the standard deviation is not always justified, particularly where the behavior of systems is observed over long periods (as is done with standards) where assumptions about noise properties are usually incorrect. To take advantage of time-series methods requires further development of the treatment of unequally spaced data. Furthermore, the ideas must be simplified if they are to be widely used. Additional work on cross-correlation methods and the modified Allan variance could lead to a more accurate assessment of noise performance, since the conventional approach tends to yield distorted results in the presence of high frequency noise.

■ **Optimal Use of Ensembles of Clocks.** The NIST time scales are based on an algorithm which intelligently combines the outputs of many clocks to arrive at a smooth time scale which is more stable and reliable than any of the constituent clocks. It is clear that algorithms can be developed to run more autonomously. Such research can lead to more widespread use of ensembling in industry and defense systems giving them the benefits of improved timing stability and reliability at minimum cost. In another application is needed to support comparisons between earth-bound atomic clocks and the regular pulsations of millisecond pulsars.

■ **Telecommunications Networks**. During the last few years, the Division has had strong interactions with the telecommunications industry regarding a range of synchronization issues. It is now clear that a larger involvement could pay good dividends for this industry. In order to contribute more effectively, NIST's unique synchronization expertise will have to be augmented with a competence that is specific to telecommunications networks. ▫

QUANTUM PHYSICS DIVISION



Overleaf

Silicon Nanocolumns. Scanning tunneling microscope (STM) images of a single and an adjacent pair of silicon nanocolumns, formed by manipulating surface silicon atoms with the STM. Each column is about 10 nm in height, with a half width of about 5 nm after correction for probe broadening of the images. By devising these manipulations and producing such 10,000-atom nanostructures, we are advancing the miniaturization of silicon integrated electronics, such as that directed towards increased computer memory capacity and processing speeds.

QUANTUM PHYSICS DIVISION

MISSION

Through the Quantum Physics Division, NIST participates in the Joint Institute for Laboratory Astrophysics (JILA), a cooperative enterprise between NIST and the University of Colorado (CU). The Division conducts long-term, high-risk research in quantum physics and related areas in support of the Nation's science and technology. The Division's objectives include:

- developing the laser as a refined measurement tool and applying it to tests of fundamental physical postulates and to measurements of physical constants and properties;
- devising and applying measurement techniques to advance understanding of critical rates and pathways for important chemical species and processes;
- researching new techniques for measuring and interpreting interactions involving electrons, atoms and molecules in ionized and excited gases;
- improving the theory and instrumentation required for measurements in both the astrophysical and geophysical domains.

The Division accomplishes its mission by interacting with University faculty and visiting scientists to maintain expertise at the forefront of research in physics; by transferring the results of its research and the technology developed to the Nation's industries and other government agencies; and by exchanging ideas and skills with other scientists in NIST and in industry through scholarly publications, visits, seminars, and exchanges of personnel.

ORGANIZATION

The 26 permanent senior scientists ("Fellows") of JILA form a governing body that sets policy, subject to review by the Director of NIST and the President of CU. A biennually-elected Chairman, assisted by an executive committee, is responsible for operating the Institute within the policies set out by the Fellows. Of the 25 active Fellows, 15 are full-time faculty members in the Departments of Physics, Chemistry, or Astrophysical, Planetary and Atmospheric Sciences (APAS); ten are NIST employees (nine in the Quantum Physics Division and one in the Time and Frequency Division). These scientists work side by side, sharing facilities and responsibility for the success of the Institute; yet each remains officially responsible to their respective employer, NIST and its Director in one case, CU and the pertinent academic department in the other.

Through their adjoint faculty appointments, NIST scientists at JILA have both the opportunity and responsibility to participate in faculty activities and to supervise graduate students and postdoctorals. Eight of the NIST scientists are Lecturers or Adjoint Professors in Physics, two are Adjoint Professors in Chemistry, and one is an Adjoint Professor in APAS. JILA is currently home to 95 graduate students and 45 postdoctorals. The Institute has 49 administrative and technical support staff, 20 senior scientific staff, and ten Visiting Fellows. At the present time, 62 graduate students and postdoctorals are being supervised by NIST scientists.

The JILA Visiting Fellows Program is probably the next most important factor in maintaining an atmosphere of change and scientific excitement in JILA. Each year it provides partial funding for some ten internationally distinguished scientists to spend up to 12 months at JILA collaborating with resident scientists. Applicants are chosen according to scholarly achievement, demonstrated interest in the scientific and technical objectives of JILA, and the recommendations of their peers. Since its inception 28 years ago, the Program has become internationally renowned and more than 270 senior scientists from the United States and 29 foreign countries have participated.

CURRENT DIRECTIONS

A direct outgrowth of the national space program in the early 1960s, JILA was formed in response to perceived serious gaps in our basic understanding of the physics of gaseous atmospheres (terrestrial, planetary, solar and stellar). JILA has since responded to changing national needs and to the requirements of its parent organizations, becoming a world leader not only in atomic and molecular science and astrophysics but also in precision measurement (including gravity and geophysics), laser and optical physics, and chemical physics. Recent scientific thrusts include:

- **New Frequency Standards.** We are contributing to the development of new optical and microwave frequency standards based on an atomic "fountain," developing a compact and manageable phase-locked system linking the optical and microwave frequency domains, and devising more accurate and transportable optical frequency standards.

- **Accurate and Precise Measurement Techniques.** We are developing laser-based and other advanced measurement techniques such as extremely sensitive interferometric and seismic isolation devices to support both ground- and space-based observations of gravitational waves from astrophysical sources, and techniques to measure key physical constants such as advanced traps for determining atomic mass to ultrahigh accuracy.

- **Measurement Techniques for Chemical Reactions.** We are developing new techniques for unraveling a variety of previously unexplored chemical reactions, such as mass- and vibrationally-selected ion reactions and reactions of doubly-charged molecular ions.

- **Scanning Tunneling Microscopy.** We are exploiting the scanning tunneling microscope (STM) as a tool for studying, at the level of individual atomic sites, the changes in reactivity and morphology of surfaces bombarded by electrons and reactant particles, and investigating measurement techniques fundamental to the development of STM-based nanofabrication.

- **New Techniques for Semiconductor Fabrication.** We are applying advanced laser techniques to the controlled laser deposition of refractory materials for the development of new semiconductor deposition techniques, and to the development of new measurement tools for characterizing etching and deposition processes and crystalline growth.

- **Excitation of Atoms and Ions by Electrons.** We are developing new techniques for making absolute measurements of electron-ion excitation cross sections for multiply-ionized atoms, and for theoretical investigations of relativistic effects in the interaction of electrons with heavy atomic systems such as occur in fusion plasmas, planetary atmospheres, and high-power switches.

HIGHLIGHTS

- **Enhanced Detection Sensitivity Uncovers Anomalous Lineshape.** Precision optical spectroscopy under conditions of optimum sensitivity is required, for example, in detection of trace materials (e.g., Krypton from surreptitious nuclear tests). In frequency standards work, to determine line center to high precision, one must know the line shape to a high confidence level. We have discovered that conditions of optimum sensitivity will lead to a lineshape somewhat different from that predicted by conventional theory.

The key finding was the unexpected evolution of the phase of the optical dipole moment with increasing laser power in laser-saturated absorption with optical heterodyne detection. Large phase-shifts ($>\pi/2$) were observed, which were first considered as a manifestation of Berry's geometrical phase in the Bloch space of the Feynmann-Vernon-Hellwarth vector.

While this effect does exist and should be observable under appropriate conditions, the larger effect actually observed is due to non-equilibrium response of the atomic polarization under the influence of the optical field, which contains near-resonant rf sidebands that can be used to enhance the detection sensitivity so dramatically. Luckily the full anti-symmetry is preserved so no degradation of laser stabilization capability ensues. Collaboration with CU theoreticians has led to this clarified understanding of this new phenomena.

- **Divide and Conquer Scheme Advances.** As part of our collaborative program with Professor T. W. Hänsch's lab at the Max Planck Institute in Garching, we are exploring phase-coherent all-optical synthesis of optical frequencies (a scheme we call "Divide and Conquer"). This will likely be the avenue toward vastly-improved working standards in the visible. Local effort has led to the operation of a nice cw frequency doubling and tripling system. We begin with ~300 mW from a laser-diode-pumped Nd:YAG oscillator at 1.06 μm (near infrared), feeding it into a ring resonator containing two nonlinear crystals. The $KNbO_3$ crystal is phase-matched at 180 °C for doubling and produces about 50 mW of green light at 532 nm. This frequency and the remaining fundamental are frequency-summed in a $LiIO_3$ crystal using angle-tuned phase-matching, and produce more than 1/4 mW continuous power at 355 nm. This may be the first demonstration of such highly-efficient generation on a continuous basis.

Another ND:YAG/doubler system is set up to produce only the doubled green light, and each system is very accurately locked to nearby transitions in the I_2 spectrum. [This Iodine spectroscopy is based on our patented scheme of "Modulation Transfer."] The ~16 GHz difference frequency between the two Doppler curves and the hyperfine structure of both of these potential reference lines has been measured, and unprecedented visible laser stability of <200 Hz absolute has been obtained for times from seconds to days.

■ **Emphasis in Laser Gravitational-Wave Observatory in Space (LAGOS) Project Shifts.** We have now shown that the size of the four individual spacecraft and the difficulty of the proposed mission can be reduced substantially. However, care was taken to make sure that no substantial loss in the expected scientific results from such a mission would result. Laser heterodyne measurements will be used to determine changes in the arm-length difference for a Michelson interferometer with 5×10^6 km arm lengths. Test masses freely floating inside four separate spacecraft in orbit around the L-5 point of the Earth-Sun system will support the end mirrors for the two arms of the interferometer.

The gravitational wave frequencies of interest are from 10^{-4} to 1 Hz. The total error allowances are now 3×10^{-15} m/s$^2/\sqrt{Hz}$ for the sum of the spurious accelerations of the four test masses for frequencies in the range from 10^{-4} to 5×10^{-2} Hz, and 1.5×10^{-11} m/$\sqrt{Hz}$ for the measurement of the difference in length of the two arms for frequencies from 10^{-3} to 1 Hz. The on-orbit mass for each spacecraft is 140 kg, and the total injected mass into the initial transfer orbit is 2000 kg, so an Atlas-Centaur launch vehicle could be used.

Work also has continued on studies of gravitational wave sources consisting of compact stars with relativistic velocities in orbit around roughly 10^6 solar mass black holes in galactic centers. Several dozen such sources are expected to be observable out to red shifts of about 2 under some plausible scenarios for conditions in galactic nuclei.

■ **Isolation Systems for Gravitational Wave Antennas Undergoing Tests.** The performance of ground-based gravitational wave antennas could be extended down to frequencies near 1 Hz through improved seismic isolation. We are working to demonstrate that a three-stage isolation system can be designed that will provide the necessary isolation without introducing too much thermal noise. During the past year a preliminary six-degree-of-freedom isolation stage with an isolation factor of 100 from 1 to 100 Hz has been constructed and it is now being tested.

A multistage system with an overall isolation factor of roughly 10^{-4} at 1 Hz and 3×10^{-7} at 10 Hz appears to be needed in order to bring the vibrational noise at the support points of the test mass pendulums down to the desired level in low-frequency interferometric detectors similar to the 4 km arm length detectors in the Laser Interferometer Gravitational-Wave Observatory (LIGO) being designed jointly by Cal Tech and MIT. The required noise level is not well known, but is in the range of 10^{-13} to 10^{-14} m/$\sqrt{Hz}$ at 1 Hz for the common mode motion of the support points for the final isolation pendulums in a low-frequency gravitational wave detector.

Each isolation stage needs to attenuate oscillations in all six degrees of freedom in order to avoid cross-coupling between the different types of motion. The preliminary stage is large enough to support a vacuum system which can contain the two planned main isolation stages. The preliminary stage also can be used later as a shake table to test the performance of the two main stages.

■ **Surface Morphology of Amorphous Silicon Films Being Probed**. Due to their low production cost and large areas, hydrogenated amorphous silicon (a-Si:H) films are a leading contender for solar electricity generation, and they are also used for thin film transistors in display and reading devices. However, for reasons that are not well understood, the properties of these devices depend critically on the plasma deposition conditions, and their electrical properties do not attain what is believed possible. A major cause of this uncertainty is an inadequate understanding of the atomic structure of this amorphous material. To clarify this we have used a scanning tunneling microscope (STM) to directly measure the atomic scale structure of the surface of these films. We found that the films initially grow very homogeneously and compactly, but with increasing thickness they degenerate into rough and relatively porous materials (on an atomic scale). Figure 1 shows an example.

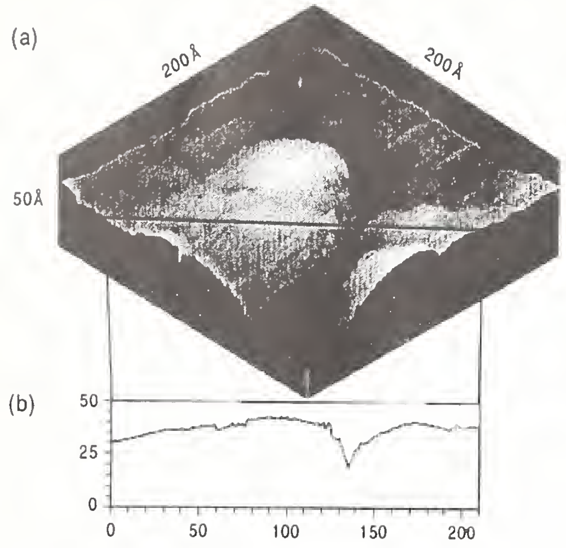


Figure 1 – STM scan of hydrogenated amorphous silicon film, with thickness profile for typical cross section.

These observations have forced a rethinking of deposition processes and plasma chemistry, as well as of the properties and defects of this semiconductor material. These results, as well as NMR and x-ray scattering observations from other laboratories, implicate small voids in the material as primary determinants of electrical imperfections. This is stimulating searches for more optimum deposition methods.

■ **Laser Ionization Probing Promises New Diagnostic of Semiconductor Growth.** The purity and concentration of materials deposited under high vacuum during semiconductor growth is a significant factor in the "art" of the fabrication processes. Lack of control of fluxes in the deposition processes can result in high failure rates and defects. Optical/laser probing of the gas phase species involved in growth of III-V and II-VI semiconductor materials by molecular beam epitaxy (MBE) is an area of high potential application.

Work is being carried out in this program to develop single-photon laser ionization methods for direct detection of the gaseous fluxes of Ga and In atoms, As_4, As_2, and As, and dopant species relevant to III-V growth. With the incorporation of non-invasive laser probes into advanced generations of MBE machines, it will be possible to carry out *in situ* diagnostics to quantify and characterize the growth process, to provide optical feedback for adjustment of species concentrations, and to determine the purities of materials used during semiconductor fabrication.

An important new technological advance was the successful incorporation of 118 nm laser ionization detection (10.5 eV per photon) into an MBE reactor. [A patent has been filed on the application of this technique to commercial MBE reactors.] The laser source is used to produce selective, single photon ionization of gaseous fluxes of Ga, In, As_4, As_2, and As species, and the ions are detected by a time-of-flight mass spectrometer. Relative photoionization cross sections have been obtained for the species Ga, As, As_2, and As_4. Atomic As desorption has been detected in the scattering and chemisorption of As_4 on a heated silicon substrate. The single photon ionization technique is applicable to essentially all of the elements used in III-V and II-VI MBE as well as most organic metal vapor species used for semiconductor growth. By using a novel geometrical arrangement in the apparatus to obtain RHEED measurements (see Fig. 2),

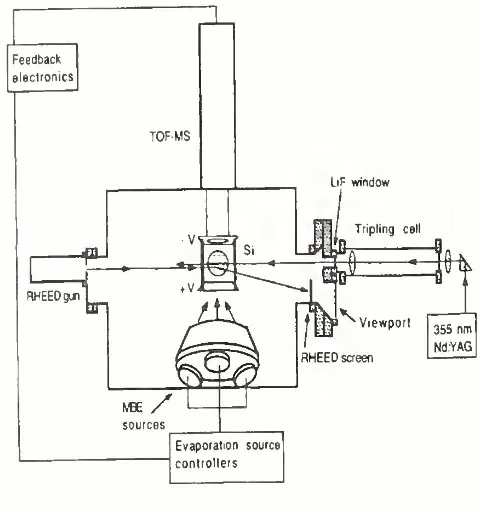


Figure 2 – Apparatus for noninvasive laser ionization probing of semiconductor growth.

we can simultaneously correlate the well-established RHEED measurements with the laser flux detection.

The 118 nm ionization method can be extended to the study of Zn, Se, S, and Cd species interacting with GaAs and Si:Ge substrates, which will provide new information relevant to the growth of $Cd_xZn_{1-x}Se/ZnS_xSe_{1-x}$ II-VI blue-green, optoelectronic semiconductor materials. The laser technique affords a major, new non-intrusive optical tool for the study of epitaxial growth.

■ Mass and Vibrationally Selected Ion Reactions Under Study. A new apparatus has been constructed to study reactions of mass selected (isotopic) and vibrationally state-specific ions. Typical considerations of charge transfer reactions would assume that the electron transfer occurs over a long range, while the molecules do not approach close enough together for vibrational energy transfer to occur. Using the new apparatus, we can test this hypothesis. This apparatus combines the flowing afterglow laser-induced fluorescence (LIF) method with a mass selected ion source, the so-called selection ion flow tube (SIFT). In the first studies with the new SIFT-LIF apparatus, symmetric charge transfer reactions involving vibrationally excited species were studied by isotopic selection, e.g. vibrationally excited $^{15}N_2^+$ and $^{14}N_2$ going to ground state $^{15}N_2$ and vibrationally excited $^{14}N_2^+$. The surprising results – simultaneous vibrational energy transfer and electron transfer is observed ≈20% of the time, both for v = 1 and v = 2 – suggest that the formation of a linear $[N_4^+]$ intermediate may occur, allowing the flow of vibrational energy across the relatively weak central bond from one N_2 subunit to the other.

Additional studies of the reaction of N_2^+ with O_2 provide new insight into the vibrational enhancement of the charge transfer rate and the competition with vibrational deactivation. The charge transfer rate is found to be constant with vibrational state v = 0, 1, and 2, while the rate of vibrational deactivation steadily increases with increasing vibrational level.

■ New Window Opens on Reactions of Doubly-Charged Molecular Ions. In a novel apparatus, this class of reactions can be studied at modest kinetic energies for the first time (50 eV). The doubly charged ions have a strong internal Coulomb repulsion which tends to cause the molecule to fragment into two singly charged ions upon collision. Nevertheless, charge transfer reactions have large cross sections and a variety of unique product species can be observed and explained by simple curve crossing theories.

More unique is the observation of several neutral fragmentation channels in polyatomic dications. For example, CF_3^{++} produces CF_2^{++} + F a large percentage of the time upon collisions with some rare gases. This neutral loss channel is explained by the unusual chemical stability of CF_2^{++} which is isoelectronic with CO_2. Finding an interesting chemical situation related to the stability of the isoelectronic neutral species, similar experiments were performed on SF_3^{++} and SF_4^{++} with identical observations. The SF_2^{++} species is isoelectronic with SO_2 and is formed by the loss of one and two neutral F atoms, respectively. These exciting results have important implications for the understanding of novel bonding arrangements previously unexplored.

■ Tunable, Pulsed Solid-state Lasers in the Visible Developed. There has been considerable interest in the development of narrow band, tunable IR pulses for pumping vibrational modes in quantum state selected clusters. We have recently developed a method for generating high resolution, (0.005 cm^{-1}) high energy (5 mJ) pulses of tunable IR light by injection seeding an optical parametric oscillator with a cw single mode ring dye laser (see Fig. 3). The optical

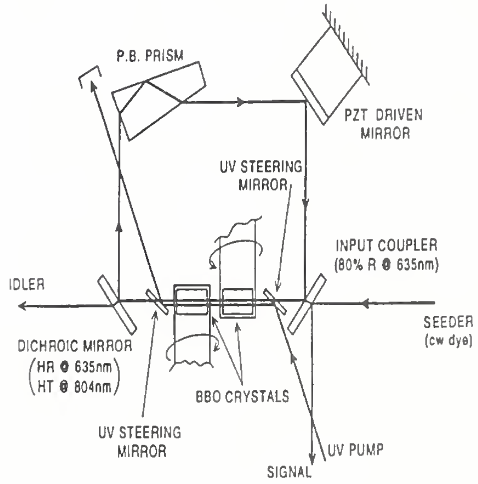


Figure 3 – Optical parametric oscillator system for generating high resolution, high energy pulses of infrared light.

parametric oscillator (OPO) is based on a ring oscillator, pumped by 355 nm (ω_3) light from a frequency tripled, injection seeded Nd:YAG laser. The OPO cavity is locked onto the dye laser via polarization servo-loop schemes, and generates intense, spectrally narrow pulsed output both at the dye laser frequency, ω_1, and the difference frequency $\omega_2 = \omega_3 - \omega_1$. With the combination of tunable diode lasers as the injection seed, this scheme could represent a novel method for generation of tunable, Fourier transform limited light pulses throughout the visible dye laser region, but entirely based on *solid state* lasers.

■ First Rotationally Resolved Spectrum of HF/DF Clusters. There has been a long standing interest in the structure of hydrogen bonded species, and in particular the high oligomers of hydrogen fluoride. Up to quite recently, it has not been possible to probe any of these oligomers with rotational resolution, due to (i) lack of any measurable dipole moment in HF trimer, tetramer etc. to permit microwave studies of the structures; and (ii) fast predissociation in the near IR which has precluded any rotational analysis.

We have recently succeeded in obtaining the first rotationally resolved spectrum of DF trimer, which represents the first resolved spectrum of any HF oligomer beyond that of the well studied dimer. The present spectra provide the first verification of the cyclic, "6-membered ring" structure of the trimer, in agreement with years of theoretical predictions. Furthermore, the spectra clearly indicate a source of homogeneous broadening (i.e., intramolecular vibrational relaxation, IVR) to a dense but discrete set of levels. At high resolution this is seen to be due to a pile up of many thousands of "sharp" lines/cm^{-1}, which indicates no predissociation of the DF trimer on a time scale of 4 ns, and yet many orders of magnitude more states than can be accounted for by a semi-rigid, "cyclic" structure. The results indicate strong IVR induced state coupling with the much higher entropy, "open chain" trimer structure in which one hydrogen bond is essentially broken by vibrational excitation. Hence, the observed homogeneous IVR widths provide a measure for DF stretch, vibrationally induced opening of the DF trimer ring, on a 40 ps time scale.

■ **Technique Shows Unexpected Phenomenon in Electron-Ion Excitation.** Measurements of absolute total cross sections for electron-impact excitation of Ar^{7+}(3s→3p) using a new merged-beams electron-energy-loss technique show that near threshold the inelastically-scattered electrons are ejected primarily in the backward direction. This unusual angular scattering has not been previously observed for atoms or ions, but may be typical for multiply-charged ions. The total cross sections, measured over an energy range to 2.2 eV above threshold, agree with seven-state R-matrix close-coupling calculations. Both close coupling and distorted-wave calculations also confirm the backscattering observed in these measurements, and surprisingly the effect can be modelled with a simple semiclassical model.

■ **Program to Trap Ions for High Accuracy Atomic Mass Measurements Advances.** A Penning ion trap has been constructed which employs a highly uniform and stable magnetic field and accurate electric fields so that one should in principle be able to make atomic mass measurements to parts in 10^{10}, and perhaps eventually to parts in 10^{12}. Masses with such accuracies play a role in possible determination of the neutrino mass, more accurate determination of Avogadro's constant, physics and chemistry of isomers, and the possible adoption of a non-artifact mass standard.

The method involves cyclotron resonance of single ions in a cold (4 K) ion trap. After demonstrating the technique, including resonance detection and measurement for ions made *in situ* by electron bombardment, recent months have been devoted to building and testing an ion source and beam line for ion injection from the outside. This will allow introduction of arbitrary species of ions and allow control of the number of ions introduced. Mass comparisons with carbon will be readily accomplished on a short time scale, for example. Though there is an extremely strong magnetic mirror reflecting ions introduced (0 to 7.5 Tesla), success has been achieved by introducing an adequate number of ions into the region normally occupied by the trap.

The trap will now be replaced and real measurements pursued. At some point, thought has been given to bringing the trap and the EBIS (electron-beam-ion-source) together and using the injection techniques developed over the recent months to introduce highly charged ions into the trap.

■ **Hubble Used in New Measurements of Electron Densities in Astrophysical Plasmas.** One of the fundamental properties of an astrophysical plasma, like that in the outer atmosphere of a star, is its electron density, which typically falls in the range of 10^7 to 10^{12} cm^{-3}. At these densities excited states of ions that are connected to the ground state by permitted transitions are generally populated by electron collisions and depopulated by radiation in the permitted transition to the ground state of the ion. On the other hand, excited states with different multiplicity (electron spin orientation) than the ground state are populated and depopulated usually by electron collisions with the ground state rather than by radiation. As a result the ratios of permitted to intersystem (i.e., forbidden) lines of the same ion or another ion formed at the same temperature are often good measures of the electron density of the emitting plasma.

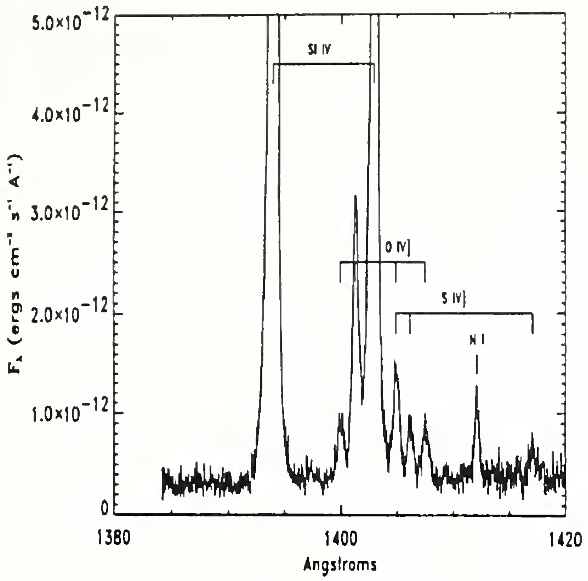


Figure 4 – High resolution ultraviolet spectrum of the star Capella obtained with the Hubble Space Telescope.

We have been using the Hubble Space Telescope (HST) to obtain high resolution ultraviolet spectra of stars that contain emission lines suitable for measuring electron densities. Figure 4 shows a portion of the ultraviolet spectrum of the star Capella that includes intersystem lines of O IV and S IV (three times ionized oxygen and sulfur). Flux ratios of these intersystem lines to permitted lines of Si IV indicate a plasma density of 4×10^{10} cm^{-3} at temperatures near 60,000 K in the atmosphere of this star.

■ **Relativistic Effects in Low-Energy Electron Scattering Under Study.** One of the first fully relativistic multichannel close-coupling calculations of electron collisions with a complex open-shell neutral atom has led to important new insights. The formalism is based on the Dirac equation, and the test case is the cesium atom, for which there are a variety of measurements and previous non-relativistic and semi-relativistic calculations. A particularly intriguing discovery was two remarkable series of very narrow (a few meV) shape resonances, as yet unobserved experimentally. Results for scattering of slow ($\leq$ 2 eV) polarized electrons clearly deviate from predictions based on simple jj-recoupling of non-relativistic results, and light emission following excitation clearly invalidates conventional assumptions that electron-impact excitation is essentially independent of fine (and also hyperfine) structure. Thorough study of this system will help us to understand the importance of relativistic interactions in electron interactions with the entire class of very heavy atoms.

■ **Patent Application Made on Technique for Cooling Solids with Lasers.** The current best means for cooling solids at low temperatures is cryogenic liquids. Cryogenic fluids are messy, expensive, and difficult to regulate and automate. Sterling cycle pumps for these fluids are unreliable and vibrate. The invention for which a patent has been applied consists of a laser beam directed onto a semitransparent crystalline solid, which by taking advantage of quantum mechanisms internal to the solid, cools it. The laser beam frequency is set to be a little lower than the direct band gap of the solid, which causes the solid to absorb the photon from the laser beam and then re-emit a photon of slightly higher frequency, i.e., energy. The result is a net loss of energy and a cooling of the solid. The invention would substitute for a Sterling refrigerator over temperatures ranging from 40 K to 200 K. It is estimated that 95 + % of Sterling refrigerators are used in this temperature range. Currently most uses of the Sterling refrigerators are for defense applications, but if high temperature semiconductors become practical, such cooling devices may be important for a wider range of applications.

FUTURE DIRECTIONS

The following is a brief summary of some of the new problems and areas of research currently planned or underway in each of the Division's four groups. The largest new effort in the next few years will be in furtherance of a Competence Proposal funded in 1991, championed by J. Hall. E. Cornell joined the Division as part of this effort.

■ **Quantum and Nonlinear Optics Competence.** The goal of the Competence Program is, by exploiting laser, nonlinear optical, and rf electronic techniques, to achieve advances in the sensitivity of optical measurements well beyond that attainable within previously accepted "quantum" limits. Potential applications include enhanced detection sensitivity for trace materials, practical *absolute* optical power standards based *entirely* on quantum physics concepts, more secure communications, ultrasensitive sideband laser spectroscopy, precise manipulation of atoms and molecules, advanced optical and microwave frequency standards, spectacular advances in atomic clocks, and novel tests of fundamental physical principles.

■ **Fundamental and Precision Measurements.** We will continue to aggressively exploit the remarkable environment presented by laser-cooled and trapped atomic samples, particularly their application in an "atomic fountain" optical frequency source. Present thinking centers on using the M2 transition $^1S_0 \rightarrow ^3P_2$ in laser-cooled Ca, but several technical problems do not yet have suitable solutions. Optical frequency synthesis continues to be of great interest, and we are now looking at a short "chain" of optical sources that can reach the visible with 7 lasers, starting with the 1.064 μm system described previously. Of particular significance for the gravitational wave detector community is the possible existence of stress-relief "events" in the laser's reference cavity that could masquerade as genuine signals. Our test setup has recently been enhanced with active vibration isolation (almost 60 dB in the sensitive, vertical direction), so only minimal environmental sensitivity is expected.

■ **Chemical Physics.** A new series of experiments will use IR laser direct absorption methods to probe the collisional alignment of molecular angular moments in supersonic jets. The approach is to use polarization modulation of a diode laser beam to sample the differential distribution of M_j projections in the laboratory frame via modulation of the absorption signal. In essence, these studies will measure the collisionally induced birefringence of molecules and probe the orientational dependence of state-to-state energy transfer cross sections. One long-term interest is in developing an intense source of oriented molecules for studying the steric influence on energy transfer and reactive collisions under molecular beam conditions.

■ **Atomic and Molecular Collisions.** In order for the optical fountain atomic clocks to reach their promise of a part in 10^{16} accuracy, novel ultra-low temperature atom-atom interactions which give rise to systematic line shifts must be brought under control. A study is underway to characterize experimentally those line-shifting collisions. Detailed measurements have been made of resonant-excitation-double-autoionization (REDA) for electron-impact of He-like ions C^{4+}, N^{5+}, and O^{6+} in the metastable triplet state. Such indirect processes can be very large for some ions, and it is important to understand them for simple systems such as these. The apparatus has been reconfigured for further ionization measurements on simple ions of fusion interest, and preliminary measurements have been made of the cross section for ionization of Cl^+. Edge plasmas of Tokamaks have ionization stages ranging from neutral to +9, and Cl is one of the elements found in the edge plasma.

■ **Astrophysical Measurements.** X rays observed by satellites with grazing incidence telescopes now show that most stars are surrounded by hot plasmas with temperatures of 10^6 to 10^7 K. Linsky and collaborators have been using the Roentgensatellit (ROSAT satellite), a collaborative space experiment of the Federal Republic of Germany and NASA, to measure the amount of hot plasma and its temperature in a variety of stars. One of the major news results of their work is the discovery of x-ray emission, and thus the existence of hot coronal plasma, surrounding the chemically peculiar B-type stars, a class of stars that had been thought to be unable to heat their atmospheres to high temperatures. Linsky co-chaired the Scientific Organizing Committee of a conference in Palermo, Italy in June 1992 that brought together the world's leading observers and theoreticians who study the hot coronae of the Sun and stars. He is editing the conference proceedings that will be called "Physics of Solar and Stellar Coronae." □

APPENDIX A

PUBLICATIONS

A

PUBLICATIONS

LABORATORY OFFICE

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Zhou, H.-L., Norcross, D.W., and Whitten, B.L., "High-precision calculations of cross sections for low energy electron scattering by ground- and excited-state of sodium," in *Correlations and Polarization in Electronic and Atomic Collisions and (e,2e) Reactions*, Inst. Phys. Conf. Ser. No. 122 (P.J.O. Teubner and E. Weigold, Eds., Inst. of Physics, Bristol, 1992), pp. 39-48.

Zhu, M., and Hall, J.L., "Short and long term stability of optical oscillators," in Proc., IEEE Frequency Control Symposium, in press.

APPENDIX B

INVITED TALKS

B

INVITED TALKS

LABORATORY OFFICE

Taylor, B.N., "Status Report on the ISO/IEC/OIML/BIPM Guide, *Expression of Uncertainty in Measurement*," 1992 Measurement Science Conference, Anaheim, CA, Jan. 1992.

Taylor, B.N., "The ISO/IEC/OIML/BIPM Guide on Uncertainty," Annual NIST/GIDEP Committee Meeting, NIST, Gaithersburg, MD, March 1992.

Taylor, B.N., "Status Report on the ISO/IEC/OIML/BIPM Guide, *Expression of Uncertainty in Measurement*," 1992 National Conference of Standards Laboratory Annual Workshop and Symposium, Washington, DC, August 1992.

Taylor, B.N., "The ISO Guide to the Expression of Uncertainty in Measurement: A Status Report," Measurement Quality Conference, American Society for Quality Control-Measurement Quality Division and NIST, Gaithersburg, MD, Nov. 1992. □

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Celotta, R.J., "Oscillations in Exchange Coupling Between Magnetic Layers," Magnetism and Magnetic Materials Conference, Houston, TX, December 2, 1992.

Celotta, R.J., "Spin Resolved Secondary Electron Microscopy," Workshop on Nucleation and Growth, University of Minnesota, St. Paul, MN, May 12, 1992.

Celotta, R.J., "The Observation of Magnetic Exchange Coupling," Physics Department, New York University, New York, NY, April 25, 1992.

Celotta, R.J., "Scanning Electron Microscopy with Polarization Analysis of Magnetic Materials," Wickenberg Conference on Microstructures of Magnetic Materials, Phoenix, AZ, January 7, 1992.

Clark, C.W., "Structure and Spectroscopy of Atoms," Summer School on Atomic and Molecular Physics and Quantum Optics, Department of Theoretical Physics, Australian National University, Canberra, Australia, six one-hour lectures, January 1992.

Clark, C.W., "Strong-field Laser-Atom Interaction: Applications of Massively Parallel Processing," Annual Meeting of the Collaborative Computational Project on Continuum States of Atoms and Molecules, University College, London, England, April 3, 1992.

Clark, C.W., "Order and Chaos in the Spectra of Highly Excited Atoms, Or Big as a Bug," Society of Physics Students, Northern Virginia Community College, Annandale, VA, April 16, 1992.

Clark, C.W., "Closed-Form Solutions of the Schroedinger Equation for a Model One-Dimensional Hydrogen Atom," Ugo Fano 80th Birthday Symposium, University of Chicago, Chicago, IL, May 23, 1992.

Kelley, M.H., "Imaging of Magnetic Microstructure With SEMPA," Physics Department Seminar, University of Delaware, Newark, DE, November 3, 1992.

Lett, P.D., "Associative Ionization in Ultracold Sodium," Physics Department Seminar, University of Connecticut, Storr, CT, February 28, 1992.

Lucatorto, T.B., "Atomic Structure Studies with Multiphoton and 'Many'-Photon Techniques," Pohong Institute of Technology, Pohong, Korea, October 28, 1992.

Lucatorto, T.B., "Resonance Ionization Studies at NIST," Korea Atomic Energy Research Institute (KAERI), Taejon, Korea, October 26, 1992.

Lucatorto, T.B., "Resonance Ionization Spectroscopy: Multiphoton and 'Many' Photon," Korean Physical Society, Seoul, Korea, October 24, 1992.

Lucatorto, T.B., "Isotopic Selectivity in RIMS/RIS," Workshop on Advanced Laser Technology for Chemical Measurements, Santa Fe, NM, October 19, 1992.

Lucatorto, T.B., "Multiphoton and Many-Photon Techniques and the Study of Atomic Structure," Physics Department Colloquium, Howard University, Washington, DC, April 22, 1992.

Madden, R.P., "Preliminary Results from the UV Round Robin Comparison," Fourth Conference on Absolute Radiometry, Baltimore, MD, October 5, 1992.

Madden, R.P., "SURF-II, The National Capital Area's Synchrotron Radiation Source," National Capital Section of the Optical Society of America, McLean, VA, April 14, 1992.

McClelland, J.J., "Spin-Polarized Electron Scattering from Laser-Excited Atoms," Physics Department Colloquium, State University of New York at Stony Brook, Long Island, NY, February 26, 1992.

Pierce, D.T., "Exchange Coupling of Magnetic Layers," IBM Almaden Research Center, San Jose, CA, November 6, 1992.

Pierce, D.T., "Influence of Structure on Exchange Coupling of Magnetic Layers," Physics Department, University of California, Berkeley, CA, November 5, 1992.

Pierce, D.T., "Investigation of Exchange Coupling of Magnetic Layers Using SEMPA," Physics Department, Stanford University, Palo Alto, CA, November 4, 1992.

Pierce, D.T., "Interlayer Exchange Coupling in Magnetic Multilayers," Physics Department Colloquium, Michigan State University, East Lansing, MI, September 29, 1992.

Pierce, D.T., "Oscillations of the Exchange Coupling in Fe/Cr/Fe(100)," US/Japan Seminar on Multimagnetic/Multilayered Structures, Lihue, HI, May 17, 1992.

Pierce, D.T., "Exchange Coupling in Magnetic Multilayers," University of Texas at Arlington, Arlington, TX, April 15, 1992.

Pierce, D.T., "Oscillations in the Exchange Coupling of Fe/Cr/Fe," March Meeting of the American Physical Society, Indianapolis, IN, March 16, 1992.

Stroscio, J.A., "Scanning Tunneling Microscopy Applied to the Growth of Materials," Materials Research Society Meeting, Boston, MA, November 30, 1992.

Stroscio, J.A., "Nucleation and Growth in Homoepitaxy of Fe on Fe(001) Whiskers," 39th National Symposium of the American Vacuum Society, Chicago, IL, November 9, 1992.

Stroscio, J.A., "Metal on Metal Growth Studied with STM and RHEED Measurements," American Chemical Society 204th National Meeting, Washington, DC, August 25, 1992.

Stroscio, J.A., "Insulating Alkali Phases on III-V Surfaces Studied with Scanning Tunneling Microscopy," Solid State Physics Seminar, Cornell University, Ithaca, NY, April 21, 1992.

Stroscio, J.A., "Atomic Manipulation with the Scanning Tunneling Microscope," March Meeting of the American Physical Society, Indianapolis, IN, March 16, 1992.

Stroscio, J.A., "Microscopic Aspects of metal on Metal Epitaxy: Comparison of STM and RHEED Measurements," Nanoelectronics ARI Seminar, Naval Research Laboratory, Washington, DC, February 25, 1992.

Stroscio, J.A., "Atomic Manipulation of Polarizable Atoms by Electric Field Induced Directional Diffusion," International Workshop on Atoms and Clusters (WAC), Atami, Shizuoka, Japan, January 8, 1992.

Stroscio, J.A., "Microscopic Aspects of Metal on Metal Epitaxy," Atomic Technology Institute, Tokyo, Japan, January 6, 1992.

Unguris, J., "SEMPA Studies of Oscillatory Exchange Coupling," NATO Advanced Research Workshop, Cargese, Corsica, France, June 16, 1992.

Watts, R.N., "XUV Optics Characterization at NIST," International Conference on the Application of Accelerators in Research and Industry, Denton, TX, November 4, 1992. □

ATOMIC PHYSICS DIVISION (842)

Gillaspy, J.D., "Probing the Two-Electron Lamb Shift with Precision Laser Spectroscopy," Department of Physics and Astronomy, State University of New York, Binghamton, NY, November 1992.

Helmerson, K., "New Types of Optical Dipole Force Traps," at Atomic Physics seminar, SUNY at Stony Brook, Stony Brook, NY, September 1992.

Kim, Y.-K., "Relativistic and Quantum Electrodynamic Effects in Atoms," Universität Kassel, Germany, March 1992.

Kim, Y.-K., "Electron-Impact Ionization Cross Sections for Atoms," Universität Kassel, Germany, March 1992.

Kim, Y.-K., "Comparison of Theoretical and Experimental Atomic Spectra: How to Identify Aliens with Multiconfiguration Dirac-Fock Method," Université de Paris IV, France, March 1992.

Kim, Y.-K., "Conference Summary," Workshop on Electron-Ion Collisions, Clark Atlanta University, Atlanta, GA, April 1992.

Kim, Y.-K., "What's New in Relativistic Atomic Structure Theory" 4th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, NIST, September 1992.

Kim, Y.-K., "Atomic Structure Calculations in Heavy Atoms," Workshop on Synchrotron Radiation in Transactinium Research, 1-2 October 1992, Lawrence Berkeley Laboratory, October 1992.

Kim, Y.-K., "Relativistic Effects in Atoms and Molecules," Physics Department Colloquium, Nara Women's University, Nara, Japan, October 1992.

Kim, Y.-K., "Relativistic and Quantum Electrodynamic Effects in Atoms," Institute of Laser Engineering, Osaka University, Suita, Japan, October 1992.

Kim, Y.-K., "Relativistic and Quantum Electrodynamic Effects in Atoms," the First East Asian International Seminar, Hachioji, Japan, October 1992.

Kim, Y.-K., "Relativistic Atomic Structure Calculations," Japan Atomic Energy Research Institute, Tokai, Japan, October 1992.

Kim, Y.-K., "What's New in Relativistic Atomic Structure Theory," Fall Meeting of the Korean Physical Society, Seoul, Korea, October 1992.

Kim, Y.-K., "Relativistic Calculations for Atoms," Physics Department Colloquium, Pohang Institute of Science and Technology, Pohang, Korea, October 1992.

Lett, P., "Laser Cooling of Neutral Atoms," Physics Colloquium, Univ. of Arkansas, Fayetteville, AR, November 1992.

Lett, P., "AI Experiments in Ultracold Sodium," Symposium on Cold Atom Collisions, Cambridge, MA, April 1992.

Mohr, P.J., "Quantum Electrodynamics Calculations in Few-Electron Systems," Nobel Symposium #85, Stockholm, Sweden, June 1992.

Phillips, W., "Laser-Cooling: the Coldest Atoms Ever," Physics Colloquium, Ohio State Univ., January 1992.

Phillips, W., "Laser Cooling," AAAS meeting, Chicago, IL, February 1992.

Phillips, W., "Laser Cooling and Trapping," Intl. Center for Theoretical Physics, Trieste, Italy, March 1992.

Phillips, W., "Laser Cooled Neutral Atom Frequency Standards," Symposium on Frequency Control, Hershey, PA, May 1992.

Phillips, W., "Laser Cooling and Trapping," short course, CLEO/QELS, Anaheim, CA, May 1992.

Phillips, W., "Laser Cooling: the coldest atoms ever," Scientist-to-Scientist Colloquium, Keystone, CO, August 1992.

Phillips, W., "Laser Cooling," Physics Colloquium, Univ. of Toronto, Toronto, Canada, October 1992.

Phillips, W., "Quantized Motion of Trapped Atoms," NASA Goddard Quantum Electronics Seminar, Goddard Space Center, MD, October 1992.

Phillips, W., "Laser Cooling and Trapping," Physics Colloquium, SUNY at Stony Brook, Stony Brook, NY, October 1992.

Phillips, W., "Quantum Motion of Optically Trapped Atoms," Modern Optics Seminar, MIT, Cambridge, MA, November 1992.

Phillips, W., "Laser Cooling: the Coldest Atoms Ever," Physics Colloquium, Argonne Natl. Lab., Argonne, IL, November 1992.

Phillips, W., "Laser Cooling: the Coldest Atoms Ever," Physics Colloquium, Univ. of Delaware, Newark, DE, December 1992.

Roberts, J.R., "Radiometric Measurements for Photolithography," NIST/DEC Semiconductor Metrology Tutorial, Hudson, MA, February 1992.

Roberts, J.R., "Spatial Argon Optical Emission Distributions in the NIST RF Reference Cell," 45th Annual Gaseous Electronics Conference, Boston, MA, October 1992.

Rolston, S., "Observation of Quantized Motion In Optical Molasses," Intl. Conf. on Atomic Physics 13, Munich, Germany, August 1992.

Rolston, S., and Phillips, W., "Laser Cooling and Manipulation of Antihydrogen," Antihydrogen Workshop, Munich, Germany, August 1992.

Rolston, S., "Observation of Quantized Motion in Optical Molasses," Shanghai Intl. Conf. on Quantum Optics, Shanghai, China, April 1992.

Rolston, S., "Trapping Atoms with Light," JILA Colloquium, Boulder, CO, January 1992.

Wiese, W.L., "Ion Broadening Contributions in the Stark Profiles of Isolated Lines," University of Kiel, Germany, May 1992.

Wiese, W.L., "Spectroscopic Data for Light-Element Plasma Impurities," Conference on Fusion Plasma Edge Studies, International Atomic Energy Agency, Vienna, Austria, June 1992.

Wiese, W.L., "Spectroscopic Coupling Schemes in the Light Elements," Hungarian Central Research Institute, Budapest, June 1992.

Wiese, W.L., "Atomic Transition Probabilities of Light Elements," Ruhr University, Bochum, Germany, July 1992.

Wiese, W.L., "Progress in Evaluated Transition Probabilities," 4th International Colloquium on Atomic Spectra and Oscillator Strengths in Astrophysics and Laboratory Plasmas, NIST, September 1992.

Wiese, W.L., "Status of Spectroscopic Atomic and Molecular Databases," Conference on Atomic and Molecular Data for Fusion Reactor Technology, Cadarache, France, October 1992. ▫

MOLECULAR PHYSICS DIVISION (843)

Casassa, M.P., "Nascent Product States of the Reaction of $O(^1D)$ and H_2O in Bimolecular Collisions and in O_3-H_2O Clusters," HEDM-AFOSR Contractors' Meeting, Lancaster, CA, April 1992.

Casassa, M.P., "Time- and State-Resolved Studies of the Unimolecular Decomposition," CLEO-QELS Conference, Anaheim, CA, May 1992.

Casassa, M.P., "Product Energy and Vector Correlations in Simple Chemical Reactions," IBM, Watson Research Center, Yorktown Heights, NY, September 1992.

Casassa, M.P., "Product Kinetic Energies, Correlations, and Scattering Anisotropy in the Bimolecular Reaction $O(^1D) + H_2O \rightarrow 2OH$," AFOSR Molecular Dynamics Contractors' Conference, Washington, DC, October 1992.

Fraser, G.T., "Large Amplitude Motions and Stark Effects as Probes of Intramolecular Vibrations Energy Redistribution," Department of Chemistry, Howard University, Washington, DC, September 1992.

Fraser, G.T., "Electric Resonance Optothermal Spectroscopy," William A. Klemperer 65th Birthday Celebration and Group Reunion, Department of Chemistry, Harvard University, Cambridge, MA, October 1992.

Fraser, G.T., "Large Amplitude Motions and Stark Effects as Probes of Intramolecular Vibrations Energy Redistribution," Department of Chemistry, University of Minnesota, Minneapolis, MN, October 1992.

Heilweil, E.J., "Vibrational Energy Dynamics in Gases, Liquids, and on Surfaces," Molecular Sciences Research Center, Battelle Pacific Northwest Laboratories, Richland, WA, July 1992.

Heilweil, E.J., "Dual Track Transient Infrared Spectroscopy of Metal Carbonyls," Gordon Conference on Vibrational Spectroscopy, Brewster Academy, Wolfeboro, NH, August 1992.

Heilweil, E.J., "Transient Infrared Spectroscopy of Molecule/Adsorbate Vibrational Dynamics," American Chemical Society National Meeting, Symposium on Chemical Applications of Nonlinear Surface Spectroscopy, Washington, DC, August 1992.

Heilweil, E.J., "Dual Track Transient Infrared Spectroscopy of Metal Carbonyls," American Chemical Society National Meeting, Washington, DC, August 1992.

Heilweil, E.J., "Applications of Transient Infrared Spectroscopy," Middle Regional Meeting of the American Chemical Society, University of Kansas, Lawrence, KS, November 1992.

Hougen, J.T., "Internal Rotation in Acetaldehyde," Telluride Summer Research Workshop, Telluride, CO, July 1992.

Hougen, J.T., "Some Thoughts on the Analysis of the Vibration-Rotation Spectrum of $H_5O_2^+$," Institute of Atomic and Molecular Science, Taipei, Taiwan, December 1992.

Hougen, J.T., "Molecular Symmetry and Spectroscopy as Applied to the Torsion-Rotation Spectrum of Acetaldehyde," Tsing Hua University, Shin Ju, Taiwan, December 1992.

Hougen, J.T., "Recent Molecular Spectroscopy and Research," Physics Department, Kanazawa University, Kanazawa, Japan, December 1992.

Jacox, M.E., "Shedding Light on the Structures and Chemical Bonding of Molecular Ions," U.S. Naval Research Laboratory Chapter of Sigma Xi, Washington, DC, May 1992.

Jacox, M.E., "The Infrared Spectra of Small Molecular Ions Trapped in Solid Neon," 47th International Symposium on Molecular Spectroscopy, Columbus, OH, June 1992.

Jacox, M.E., "Molecular Spectra of Intermediates in Nitramine Decomposition and Combustion Trapped in Solid Neon and Argon," Gordon Research Conference on the Chemistry of Energetic Materials, New Hampton, NH, June 1992.

Julienne, P.S., "Calculation of Loss Rates for Alkali Traps," Symposium on Cold Atom Collisions at the institute for Theoretical Atomic and Molecular Physics at the Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, April 1992.

Julienne, P.S., "The Strange World of Ultracold Atomic Collisions," James Franck Institute Seminar, The University of Chicago, Chicago, IL, May 1992.

Julienne, P.S., "Optical Manipulation of Ultracold Atomic Collisions," Gaseous Electronics Conference, Boston, MA, October 1992.

Julienne, P.S., "The Strange World of Ultracold Atomic Collisions," Physics Colloquium, Temple University, Philadelphia, PA, October 1992.

Julienne, P.S., "Optical Bloch Equation Theory of the Collisions of Laser Cooled Atoms," Laboratoire des Collisions Atomiques et Moleculaires, Orsay, France, November 1992.

King, D.S., "Having Fun with $^2\Pi$ Molecules," National Meeting of the American Chemical Society, Symposium on Dynamics on Multiple Potential Surfaces, San Francisco, CA, April 1992.

King, D.S., "Interfragment Correlations in the Vibrational Predissociation of NO-HF(v = 1)," Atomic and Molecular Interactions GRC, New London, NH, July 1992.

Lafferty, W.J., "High Resolution IR Spectroscopic Studies on Atmospheric Molecules," Laboratoire de Physique Moleculaire et Applications, Orsay, France, October 1992.

Lovas, F.J., "Fourier Transform Microwave Spectroscopy at NIST," Exxon Corporate Research Laboratory, Clinton, NJ, January 1992.

Lovas, F.J., "Molecular Structure Determinations of Weakly-Bouna Complexes," 14th Austin Symposium on Molecular Structure, Austin, TX, March 1992.

Mies, F.H., "Hyperfine Changing Collisions of Ultracold Rb Atoms," Symposium on Cold Atom Collisions, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, April 1992.

Mies, F.H., "Factoring Sequences of Dynamic Processes in a Single Collision," NATO Workshop on Dissociative Recombination, France, September 1992.

Mies, F.H., "Stabilization of H_2^+ in Intense Laser Fields," Gordon Conference on Multiphoton Processes, NH, June 1992.

Suenram, R.D., "Using van der Waals Complexes to View Reaction Pathways," Department of Chemistry Seminar at Arizona State University, Tempe, AZ, March 1992.

Suenram, R.D., "Using van der Waals Complexes to View Reaction Pathways," Department of Chemistry Seminar, University of Connecticut, Storrs, CT, April 1992. ▫

RADIOMETRIC PHYSICS DIVISION (844)

Asmail, C.C., "Bidirectional Scattering Metrology," (presented by L.M. Hanssen), Greenbelt, MD, 19-20 May 1992, Council for Optical and Radiation Measurement 1992 Annual Meeting.

Cromer, C.L., "What's a UV Meter?," UV Symposium at SPIE meeting in San Diego, CA, July 1992. (co-authors B.C. Johnson and A.E. Thompson)

Cromer, C.L., "Diode Array Spectrometer Calibration," CORM Session on Diode Array Radiometer at the SPIE meeting, Orlando, FL, April 1992.

Cromer, C.L., "Calibration Source Verification," 5th Meeting of the NASA EOS Calibration and Data Product Validation Group, Boulder, CO, May 1992.

Cromer, C.L., "The New NIST Candela," Physics Laboratory Colloquium, NIST, Gaithersburg, MD, June 1992.

Cromer, C.L., "Impact of High Accuracy Cryogenic Radiometry on Optical Standards," National Capital Section, Optical Society of America, Washington, DC, November 17, 1992.

Datla, R.U., "Two Step Traceability of Cryogenic Blackbodies to NIST Calibration Standards," Third Annual SDL/USU Symposium on Infrared Radiometric Sensor Calibration, Logan, UT, 1992.

Eppeldauer, G., "Derivation of the Luminous Intensity Scale from the Illuminance Scale," Measurement Science Conference, Anaheim, CA, 1992.

Eppeldauer, G., "Luminous-Intensity Measurements of Sources using a New Detector-Based Illuminance Scale," SPIE International Symposium on OE/Aerospace Sensing, Orlando, FL, 1992.

Gupta, D., "Standard of Spectral Reflectance at Glancing Incidence for the Infrared Region," Newrad '92 Conference, Baltimore, MD, 1992.

Hanssen, L.M., "Effect of Non-Lambertian Coatings on Integrating Sphere Measurements," Greenbelt, MD, 19-20 May 1992, Council for Optical and Radiation Measurement 1992 Annual Meeting.

Hanssen, L.M., "Infrared Diffuse Reflectance," Annapolis, MD, 9-10 June 1992, 1992 Navy Metrology Research & Development Requirements Conference.

Houston, J., "Comparison of NIST High Accuracy Cryogenic Radiometer and the NIST Scale of Detector Spectral Response," Newrad '92 Conference, Baltimore, MD, 1992.

Johnson, B.C., "The NIST Radiance Temperature Scale," Measurement Service Conference, Anaheim, CA, February 1992 (co-authors R.D. Saunders, V.I. Sapritsky, and K.D. Mielenz).

Johnson, B.C., "Realization of New NIST Radiation Temperature Scales for the 1000 K to 3000 K Region, Using Absolute Radiometric Techniques," 7th Temperature Symposium, Toranto, Canada, April 1992 (co-authors R.D. Saunders, V.I. Sapritsky, and K.D. Mielenz).

Lorentz, S., "Comparison Between the NIST LBIR Absolute Cryogenic Radiometer and an Optical Trap Detector," Newrad '92 Conference, Baltimore, MD, 1992.

Lorentz, S., "NIST LBIR Facility Spectral Calibration Capabilities," Third Annual SDL/USU Symposium on Infrared Radiometric Sensor Calibration, Logan, UT, 1992.

Migdall, A., "Measuring Filter Attenuation in Infrared," Third Annual SDL/USU Symposium on Infrared Radiometric Sensor Calibration, Logan, UT, 1992.

Migdall, A., "Ambient IR Detector Spectral Calibration at NIST," Third Annual SDL/USU Symposium on Infrared Radiometric Sensor Calibration, Logan, UT, 1992.

Migdall, A., "Characterization of a High Sensitivity Bolometer," Newrad '92 Conference, Baltimore, MD, 1992.

Makai, J., "Application of Optical Biasing Methods to Determine Temperature Induced Nonlinearities of Photovoltaic Ge Detectors," Newrad '92 Conference, Baltimore, MD, 1992.

Ohno, Y., "The New NIST Candela Scale and Future Plans," presented at IES/TPC Meeting, October 9, 1992, McLean, VA.

Parr, A., "IR Radiometry at NIST," Third Annual SDL/USU Symposium on Infrared Radiometric Sensor Calibration, Logan, UT, 1992.

Sapritzky, V., "Spectral Irradiance Scale Based on the Cryogenic Absolute Radiometer," Newrad '92 Conference, Baltimore, MD, 1992.

V. Sapritzky, "Diode Array Radiometer in USSR," CORM Session on Diode Array Radiometer at the SPIE meeting, Orlando, FL, April 1992.

Sapritzky, V., "Temperature Measurement in Radiometry," 7th Temperature Symposium, Toronto, Canada, April 1992 (co-authors S.P. Morozova and B.B. Khlevony).

Saunders, R.D., "Errors in Radiometric Measurement using Array Radiometers," CORM Session on Diode Array Radiometer at the SPIE meeting, Orlando, FL, April 1992.

Walker, J.H., "A Determination of the Freezing Temperature of Sodium Chloride," 7th Temperature Symposium, Toronto, Canada, April 1992 (co-author Q. Zhur). ▫

QUANTUM METROLOGY DIVISION (845)

Caticha, A., "The Emission of X-Rays by Fast Electrons in Crystals," State University of New York at Albany, Physics Colloquium, April 6, 1992.

Caticha, A., "The Quantum Theory of Dynamical Cerenkov Emission of X-Rays," University of Vermont, Physics Colloquium, May 19, 1992.

Caticha, A., "Dynamical Theory of X-Ray Diffraction by Multilayered Structures," SPIE Annual Conference, San Diego, CA, July 20-25, 1992.

Chantler, C.T., "Towards Improved Form Factor Tables," International Conference on Anomalous Scattering, Malente/Hamburg, Germany, August 17-21, 1992.

Chantler, C.T., "Developments in Computation of Form Factors," 4th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, Gaithersburg, MD, September 14-17, 1992.

Danos, M., "Quark Gluon Has Been Detected," Physics Colloquium, Enrico Fermi Institute, University of Chicago, May 5, 1992.

Danos, M., "Entropy in Quantum Physics," Physics Colloquium, Enrico Fermi Institute, University of Chicago, June 3, 1992.

Danos, M., "Entropy in Quantum Physics," Frankfurt, Germany, July 1992.

Danos, M., "Entropy in Quantum Physics," Bochum, Germany, July 1992.

Danos, M., "Entropy in Quantum Physics," Bonn, Germany, July 1992.

Danos, M., "Entropy in Quantum Physics," Tübingen, Germany, July 1992.

Danos, M., "Entropy in Quantum Physics," Heidelburg, Germany, July 1992.

Danos, M., "Entropy in Quantum Physics," NATO Advanced Study Institute, Pascoli, Italy, July 15, 1992.

Deslattes, R.D., Summary talk, Atomic and Molecular Physics Session, X-Ray Laser Applications Workshop, San Francisco, CA January 12-14, 1992.

Deslattes, R.D., "Precision Metrology and Fundamental Physics in the X-Ray and Gamma-Ray Regions," Nanotechnology Division Seminar, National Research Laboratory, Tsukuba, Japan, March 19, 1992.

Deslattes, R.D., "Threshold Spectroscopies of Large Atoms and Small Molecules," Spring-8 Meeting, Himeji, Japan, March 22-25, 1992.

Deslattes, R.D., "Simplicities and Complexities of Near-Threshold X-Ray Spectroscopy," National Laboratory for High Energy Physics Seminar, Photon Factory, Tsukuba, Japan, March 26, 1992.

Deslattes, R.D., "The Gamma-Ray to Red-Light Connection: What Can it do for Physics"? Physics Department, Louisiana State University, April 15-16, 1992.

Deslattes, R.D., "X-Ray Processes Near Thresholds: Is Lifetime Broadening Optional"? Physics Department, Louisiana State University, April 15-16, 1992.

Deslattes, R.D., "Experimental Aspects and Z-Dependent Systematics in One- and Two-Electron Ions and Single Vacancy Systems," Opening lecture, Nobel Symposium, Stockholm, Sweden, June 29, 1992.

Deslattes, R.D., "Recent Progress in X-Ray Diffraction and Spectrometries," Central Bureau for Nuclear Measurement Institute, Geel, Belgium, October 2, 1992.

Deslattes, R.D., "History of High Resolution Gamma Spectroscopy," Workshop on Applications of High Resolution Gamma Spectroscopy in Studies of Atomic Collisions and Nuclear Lifetimes, Institut Laue-Langevin, Grenoble, France, October 6, 1992.

Deslattes, R.D., "Spectroscopic and Structural Studies with Synchrotron Radiation: Simplicity and Complexity in Spectra Excited Near Threshold: Diffraction with Controlled Internal Wavefields," European Synchrotron Radiation Facility Colloquium, France, October 13, 1992.

Henins, A., "X-Rays in Laboratory and in the Field," New Mexico State University, Las Cruces, NM, September 17, 1992.

Kessler, E.G., Jr., "Measurements of Femtosecond Nuclear Lifetimes by the Gamma-Ray Induced Doppler Method," Spring APS Meeting, Washington, DC, April 1992.

Kessler, E.G., Jr., "Sub-Nanometer Metrology for X-Ray and Gamma-Ray Wavelength Measurements," ASPE Spring Topical Meeting on Precision Interferometric Metrology, Tucson, AZ April 7-9, 1992.

Kessler, E.G., Jr., "The Double Crystal Spectrometer GAMS4," Workshop on Applications of High Resolution Gamma Spectroscopy in Studies of Atomic Collisions and Nuclear Lifetimes, Institut Laue-Langevin, Grenoble, France, October 6, 1992.

Levin, J.C., "Observation of Double Photoionization of Helium Far Above Threshold," International Conference on the Application of Accelerators in Research & Industry, Denton, TX, November 2-5, 1992. ▫

IONIZING RADIATION DIVISION (846)

Bensen, D.L., "Calibrations of Radiation Monitoring Instruments in the NIST Radiation Interactions and Dosimetry Group," DoD Working Group Conference on Radiation Monitoring Instruments, Berryville, VA, October 1992.

Calhoun, J.M., "Standards for Radionuclides Used in Therapeutic Medicine," Poster Session, LSC92 International Conference on Advances in Liquid Scintillation Spectrometry, Vienna, Austria, September 1992.

Carlson, A.D., "The Data Base of the Standards and Related Cross Sections after ENDF/B-VI," Symposium on Nuclear Data Evaluation Methodology, Brookhaven National Laboratory, Upton, NY, October 1992.

Caswell, R.S., "Physical and Chemical Dosimetry," Radiation Research Society Annual Meeting, Salt Lake City, UT, March 1992.

Caswell, R.S., "Committee on Interagency Radiation Research and Policy Coordination (CIRRPC) Science Activities," CIRRPC Policy Meeting, Washington, DC, December 1992.

Coursey, B.M., "Use of Radiochromic Film and Alanine/EPR Passive Dosimeters in Dosimetry for Proton Beams Used in Radiation Therapy," Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia, September 1992.

Coursey, B.M., "Dosimetry Standards for Radiation Therapy in the United States," Mendeleyev Institute of Metrology (VNIIM), St. Petersburg, Russia, September 1992.

Coursey, B.M., "The Commonality of Ionizing Radiation Measurements and Standards," Council on Ionizing Radiation Measurements and Standards, Gaithersburg, MD, October 1992.

Coursey, B.M., "Reconstruction Dosimetry for the Maryland Accelerator Accident," Oak Ridge Associated Universities, Oak Ridge, TN, November 1992.

Desrosiers, M.F., "Alanine Dosimetry," Second International Workshop on Dosimetry for Radiation Processing, College Park, MD, October 1991.

Desrosiers, M.F., "Irradiated Food Detection, Radiation Accidents and Radiation Therapy. Applications of EPR Spectrometry," American Chemical Society Meeting, Penn State, York, PA, February 1992.

Desrosiers, M.F., "NIST Activities in Irradiated Food Processing," R&D Associates Annual Meeting, Arlington, VA, March 1992.

Desrosiers, M.F., "Irradiated Food Detection, Radiation Accidents and Radiation Therapy. Applications of EPR Spectrometry," American Nuclear Society/Health Physics Society Meeting, Hershey, PA, May 1992.

Desrosiers, M.F., "The NIST Alanine Dosimeter," Solid State Dosimetry Conference, Washington, DC, July 1992.

Desrosiers, M.F., "Advanced Radiation Sensors," Defense Nuclear Agency Technology Transfer Conference, Alexandria, VA, December 1992.

Dewey, M.S., "Measurement of the Neutron Lifetime," International Symposium on Weak and Electromagnetic Interactions in Nuclei, Dubna, Russia, June 1992.

Domen, S.R., "The NIST Absorbed Dose Calorimeter," National Research Council, Ottawa, Canada, December 1992.

Greene, G.L., "Neutron Beta Decay as a Test of the Standard Model," XIIth Moriond Conference on Tests of Fundamental Laws in Physics, Les Arcs, France, January 1992.

Greene, G.L., "The Properties of the Free Neutron," Central Bureau for Nuclear Measurements, Geel, Belgium, February 1992.

Greene, G.L., "Cold and Old and Ultra Cold Neutrons as a Probe for the Investigation of Fundamental Interactions," Los Alamos National Laboratory, February 1992.

Greene, G.L., "The Determination of the Neutron Lifetime," American Physical Society Division of Nuclear Physics, October 1992.

Greene, G.L., "Neutron Beta Decay, The Big Bang and the Left Handed Universe," University of Minnesota Department of Materials Science Colloquium, October 1992.

Greene, G.L., "Neutron Beta Decay: A Precise Low Energy Test of the Standard Model," Brookhaven National Laboratory, USA Physics Facilities, October 1992.

Greene, G.L., "Neutron Beta Decay, The Big Bang and the Left Handed Universe," University of Missouri Physics Colloquium, November 1992.

Greene, G.L., "^{3}He Spin Filters for Neutrons," University of Missouri Research Reactor Seminar, November 1992.

Greene, G.L., "Neutron Beta Decay: A Precise Low Energy Test of the Standard Model," Nuclear and Particle Physics Seminar, Massachusetts Institute of Technology, December 1992.

Humphreys, J.C., Walker, M.L., Puhl, J.M., Dick, C.E., and McLaughlin, W.L., "Calibration of High-Energy Electron Beams by Use of Graphite Calorimeters," 12th International Conference on Applications of Accelerators in Research and Industry, Denton, TX, November 1992.

Inn, K.G.W., "Traceability for Radiobioassay Programs," Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Ottawa, Canada, October 1991.

Inn, K.G.W., "DOE/EM's Analytical Services Program," Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Ottawa, Canada, October 1991.

Inn, K.G.W., and Collé, R., "Expression of Uncertainty in Measurement: A Primer on a Proposed ISO Guide," Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Santa Fe, NM, October 1992.

Inn, K.G.W., "Low-level Radioactivity Ocean Sediment Standard Reference Material," Conference on Low-level Measurements of Actinides and Long-lived Radionuclides in Biological and Environmental Samples, Rio de Janeiro, Brazil, October 1992.

Krey, P.W., Fiener, M.S., McInroy, J., Miglio, J., Inn, K.G.W., and Hutchinson, J.M.R., "A Bone Ash Standard for ^{90}Sr, ^{210}Pb, ^{210}Po, Uranium, and the Actinides," Conference on Low-level Measurements of Actinides and Long-lived Radionuclides in Biological and Environmental Samples, Rio de Janeiro, Brazil, October 1992.

McLaughlin, W.L., "Dosimetry: New Approaches," International Conference on Radiation-Tolerant Plastic Scintillator and Detectors, Tallahassee, FL, April 1992.

McLaughlin, W.L., "Radiation Effects on Fiber Optics," Danish-Polish Conference on Radiation Chemistry and Physics, Risϕ National Laboratory, Roskilde, Denmark, May 1992.

McLaughlin, W.L., "Quality Control for Industrial Radiation Applications," Environmental Science and Technology Department Seminar, Risϕ National Laboratory, Roskilde, Denmark, May 1992.

McLaughlin, W.L., "ESR Dosimetry," 10th International Conference on Solid State Dosimetry, Georgetown University, Washington, DC, July 1992.

McLaughlin, W.L., "Radiochromic Systems and Electron Spin Resonance Dosimeters for Use in Radiation Detection," DoD Working Group Conference on Radiation Monitoring Instruments, Berryville, VA, October 1992.

McLaughlin, W.L., "Chemical Dosimetry Standards," Radiation Science Students and Faculty, Georgetown University Medical School, November 1992.

McLaughlin, W.L., "Radiation Chemistry of Leuco Dyes and Porphyrin Solutions Used for Processing Dosimetry," Meeting of Reaction Kinetics Committee and the Radiation Chemistry Committee of the Hungarian Academy of Sciences, Budapest, Hungary, December 1992.

McLaughlin, W.L., "Radiation Dosimetry," 38th Meeting of Blood Products Advisory Committee, Food and Drug Administration, Rockville, MD, December 1992.

McLaughlin, W.L., "Documentation of Radiation Dose," 38th Meeting of Blood Products Advisory Committee, Food and Drug Administration, Rockville, MD, December 1992.

Schwartz, R.B., "ROSPEC Calibration," DNA Radiation Risk Assessment Program Coordination and Planning Meeting, La Jolla, CA, March 1992.

Schwartz, R.B., "The ICRU Operational Quantities," Eleventh Annual International Panasonic TLD Users Symposium, St. Simons Island, GA, June 1992.

Schwartz, R.B., "Overview of Bubble Dosimetry," Super Heated Drop (Bubble) Dosimetry - Applications Workshop, AFRRI, July 1992.

Schwartz, R.B., "The ICRU Operational Quantities," Alabama Health Physics Society, Huntsville, AL, November 1992.

Unterweger, M.P., Hutchinson, J.M.R., and Hodge, P.A., "NIST Traceability Measurements and Calibrations of DoD Radiac Monitoring Systems," Berryville, VA, October 1992.

Walker, M.L., "Novel Radiation Dosimetry Techniques," Norfolk State University, December 1991.

Walker, M.L., "Remote Real-Time Dose Measurements of Photon and Electron Beams with Radiochromic Films," 12th International Conference on the Application of Accelerators in Research and Industry, Denton, TX, November 1992.

Walker, M.D., "The Development of the NIST L100 X-ray Beam," CRCPD Calibration Laboratory Workshop, Sacramento, CA, September 1992.

Walker, M.D., "The CRCPD Accredited Laboratories and Role of NIST," CRCPD Calibration Laboratory Workshop, Sacramento, CA, September 1992.

Walker, M.D., "NIST Measurement Quality Assurance," CRCPD Calibration Laboratory Workshop, Sacramento, CA, September 1992. □

TIME AND FREQUENCY DIVISION (847)

Bergquist, J.C., "Ultranarrow Atomic Resonances," 22nd Winter Colloquium on Quantum Electronics, Snowbird, UT, January 1992.

Bergquist, J.C., "Ultrahigh Resolution Spectroscopy; Stable Lasers," International School of Physics, 'Enrico Fermi,' Varenna, Italy, June 1992.

Bergquist, J.C., "Ultrahigh Resolution Spectroscopy; Atomic Spectroscopy," International School of Physics, 'Enrico Fermi,' Varenna, Italy, June 1992.

Bergquist, J.C., "Metrology, Spectroscopy and Quantum Measurements," SPIE, Boston, MA, November 1992.

Bollinger, J.J., "NIST Penning Trap Work," Workshop on Nonneutral Plasmas in Traps, Irvine, CA, July 1992.

Bollinger, J.J., "Experimental Results on Normal Modes in Cold, Pure Ion Plasmas," International Conference on the Physics of Strongly Coupled Plasmas, University of Rochester, Rochester, NY, August 1992.

Bollinger, J.J., " Liquid and Solid Behavior of Cold, Trapped Ions," Ohio State Physics Department, Columbus, OH, October 1992.

Drullinger, R.E., "Cesium Atomic Clocks: A Study in Applied Atomic Physics and Error Analysis," Atomic and Molecular Seminar, Physics Dept., Austin, TX, April 1992.

Drullinger, R.E., "Potential for Diode Laser Pumped Rubidium," IEEE Symposium on Frequency Control, Hershey, PA, May 1992.

Drullinger, R.E., "Ultra High Stability Synthesizer for Diode Laser Pumped Rubidium," IEEE Symposium on Frequency Control, Hershey, PA, May 1992.

Drullinger, R.E., "The new NIST Primary Standard for Frequency," CPEM '92, Paris, France, June 1992.

Evenson, K.M., "Far Infrared Laser Magnetic Resonance of Ions," Arizona State University, Tempe, AZ, April 1992.

Evenson, K.M., "MIM and Schottky Diodes as Laser Frequency Multipliers and Mixers," IEEE Symposium on Frequency Control, Hershey, PA, May 1992.

Evenson, K.M., "Far Infrared Tunable Spectroscopy," International School of Physics, 'Enrico Fermi,' Varenna, Italy, June 1992.

Evenson, K.M. "Far Infrared Spectroscopy: Laser Magnetic Resonance," International School of Physics, 'Enrico Fermi,' Varenna, Italy, June 1992.

Evenson, K.M., "Final Measurement of Speed of Light," Oregon State University, Corvallis, OR, October 1992.

Hollberg, L.W., "Diode Lasers and Metrology," Europhysics School of Quantum Electronics, Solid State Lasers: New Developments and Applications, Elba, Italy, September 1992.

Hollberg, L.W., "Precision Measurements with Diode Laser," National Research Center, Ottawa, Canada, October 1992.

Hollberg, L.W., "Frequency-Stabilized Semiconductor Lasers I," International Society for Optical Engineering, Boston, MA, November 1992.

Hollberg, L.W., "Are Precision Measurements Possible with Diode Lasers"? International Conference on Lasers '92, Houston, TX, December 1992.

Itano, W.M., "Ultra-high Precision Spectroscopy for Fundamental Physics," 9th International Conference on Hyperfine Interactions, Osaka, Japan, August 1992.

Itano, W.M., "Quantum Measurements of Trapped Ions," 9th International Conference on Hyperfine Interactions, Tokyo, Japan, August 1992.

Itano, W.M., "The Quantum Zeno Non-Paradox and other Experiments in Quantum Measurement," Colorado School of Mines, Golden, CO, October 1992.

Levine, J., "Measurement Methods and Algorithms for Comparison of Local and Remote Clocks," 24th Annual Precise Time and Time Interval Applications and Planning Meeting, (PTTI), McClean, VA, Dec. 2, 1992.

Weiss, M.A., "Near a Description of the Global Positioning System Time Dissemination System," Space Environmental Laboratory, Environmental Research Laboratories, Office of Atmospheric Research, NOAA, Boulder, CO, September 1992.

Wineland, D.J., "Experiments on Laser Cooled Ions," American Association for the Advancement of Science Meeting, Chicago, IL, February 1992.

Wineland, D.J., "Single Atom Clocks," NIST Colloquium, Gaithersburg, MD, March 1992.

Wineland, D.J., "Laser-Cooled Positron Source," Workshop on Nonneutral Plasmas in Traps, National Academy of Sciences, Irvine, CA, July 1992

Wineland, D.J., "Single-Atom Clocks," IBM, Holmdel, NJ, August 1992.

Wineland, D.J., "Correlated Atomic States and Quantum Noise Suppression," Workshop on Atomic Coherence and Interference in Quantum Optics, Crested Butte, CO, September 1992.

Wineland, D.J., "Spin-Squeezing and Reduced Quantum Fluctuations in Spectroscopy," University of California, San Diego, CA, October 1992.

Walls, F.L. "Environmental Sensitivities of Quartz Crystal Oscillators," IEEE Ultrasonics, Ferroelectrics, and Frequency Control, Dallas TX, Feb. 18, 1992.

Walls, F.L. "Designing for Frequency and Time Metrology at the 10^{-18} Level," 6th European Frequency and Time Forum, The Netherlands, March 18, 1992.

Walls, F.L. "Secondary Standard for PM and AM Noise at 5, 10 and 100 MHz," IEEE Symposium on Frequency Control, Hershey, PA, May 27, 1992.

Walls, F.L. "A New Model of 1/f Noise in BAW quartz Resonators," IEEE Symposium on Frequency Control, Hershey, PA, May 28, 1992.

Walls, F.L., "Local Oscillator Requirements and Strategies for the Next Generation of High Stability," IEEE Symposium on Frequency Control, Hershey, PA, May 29, 1992.

Walls, F.L. "Local Oscillator Requirements and Strategies for the Next Generation of High Stability," IEEE Symposium on Frequency Control, Hershey, PA, May 29, 1992. □

QUANTUM PHYSICS DIVISION (848)

Bender, P.L., "Atmospheric refraction and satellite laser ranging," Symposium on Refraction of Transatmospheric Signals in Geodesy, The Hague, The Netherlands, May 1992.

Bender, P.L., "Active/passive vibration isolation systems for frequencies down to 1 Hz," Workshop on the Detection of Gravitational Waves, Bad Honnef, Germany, June 1992.

Bender, P.L., "Proposed microwave transponders for early lunar robotic landers," COSPAR Symposium on Astronomy and Space Science from the Moon, Washington, DC., September 1992.

Bender, P.L., "LAGOS: a mission for low frequency gravitational wave astronomy," European Space Agency Workshop on Gravitational Wave Detection, Paris, France, October 1992.

Cornell, E., "An experimental route to Bose condensation," University of Colorado, Boulder, CO, January 1992.

Cornell, E., "Getting to Bose condensation in an atom trap," Massachusetts Institute of Technology, Cambridge, MA, February 1992.

Cornell, E., "Getting to Bose condensation in an atom trap," Haverford College, Haverford, MA, February 1992.

Cornell, E., "Magnetically trapped atoms, cold collisions, and Bose condensation," Colorado State University, Fort Collins, CO, September 1992.

Faller, J.E., "History of lunar laser ranging," Moriond after dinner talk, Les Arcs, France, February 1992.

Faller, J.E., "Experiences with technology transfer," Technology transfer talks for Federal Executive Seminar Program in Denver, Boulder, CO, March 1992.

Faller, J.E., "Experiences with technology transfer," Present talk and participate as member of panel at Indianapolis Meeting of Federal Laboratory Consortium, May 1992.

Gallagher, A., "Atomic and molecular physics in silane discharges," 1992 Division of Atomic and Molecular and Optical Physics, American Physics Society, Chicago, IL, May 1992.

Hall, J.L., "Ultrastable lasers," Keynote address at International Conference on Quantum Electronics, IQEC, Vienna, Austria, June 1992.

Hall, J.L. "Stabilized lasers -- a parochial review," OPTCON '92: SPIE Symposium on Stable Lasers, Boston, MA, November 1992.

Hall, J.L., "Super stabilized lasers -- an overview," Lasers '92, Houston, TX, December 1992.

Leone, S.R., "The competition between reaction and energy transfer in fast atom collisions," American Chemical Society Meeting, San Francisco, CA, April 1992.

Leone, S.R., "The torques and forces between molecules: Laser probing of stereochemical effects," W. Albert Noyes, Jr./Mobay Memorial Lectures, University of Rochester, Rochester, NY, April 1992.

Leone, S.R., "Lasers and semiconductors -- from growth to etching," W. Albert Noyes, Jr./Mobay Memorial Lectures, University of Rochester, Rochester, NY, April 1992.

Leone, S.R., "Doppler velocity probing of collision dynamics," W. Albert Noyes, Jr./Mobay Memorial Lectures, University of Rochester, Rochester, NY, April 1992.

Leone, S.R., "Laser probing of orbital alignment dynamics," Institute of Atomic and Molecular Science, Academia Sinica, National Taiwan University, Taipei, Taiwan, May 1992.

Leone, S.R., "Lasers and semiconductors - from growth to etching," Institute of Atomic and Molecular Science, Academia Sinica, National Taiwan University, Taipei, Taiwan, May 1992.

Leone, S.R., "Time-resolved Fourier transform infrared of photofragmentation and collision dynamics," National Tsing Hua University, Hsinchu, Taiwan, May 1992.

Leone, S.R., "Lasers and semiconductors — from growth to etching," National Tsing Hua University, Hsinchu, Taiwan, May 1992.

Leone, S.R., "An introduction to lasers in mass spectrometry," American Society for Mass Spectrometry, Washington, DC, June 1992.

Leone, S.R., "The torques and forces between molecules: Laser probing of stereochemical effects," Distinguished Summer Lecturer for

1992, Northwestern University, Evanston, IL, June 1992.

Leone, S.R., "Lasers and semiconductors -- from growth to etching," Distinguished Summer Lecturer for 1992, Northwestern University, Evanston, IL, June 1992.

Leone, S.R., "Probing collision dynamics by time-resolved FTIR," Distinguished Summer Lecturer for 1992, Northwestern University, Evanston, IL, June 1992.

Leone, S.R., "Three vector correlations in atomic orbital alignment dynamics," IX European Conference on Dynamics of Molecular Collisions, Prague, Czechoslovakia, September 1992.

Leone, S.R., "Lasers and semiconductors — from growth to etching," Battelle Pacific Northwest Laboratory, Richland, WA, September 1992.

Leone, S.R., "The torques and forces between molecules: Laser probing of stereochemical effects," University of Washington, Seattle, WA, September 1992.

Leone, S.R., "Silicon etching by translationally fast beams of atoms and molecules," American Vacuum Society 1992 39th National Symposium, Chicago, IL, November 1992.

Leone, S.R., "Three vector correlations of aligned orbitals: Coherence effects denoting azimuthal symmetry," NATO Advanced Research Workshop on Orientation and Polarization Effects in Chemical Reaction Dynamics, Assisi, Italy, November 1992.

Linsky, J.L., "Measuring the deuterium abundance of the universe with the Hubble Space Telescope," NIST Physics Laboratory Seminar, Gaithersburg, MD, January 1992.

Linsky, J.L., "What are we learning about stellar activity from HST and ROSAT?" NOAO Space Environment Laboratory, Boulder, CO, February 1992.

Linsky, J.L., "Scientific results from GHRS studies of cool stars and the interstellar medium," The Pittsburgh Conference, New Orleans, LA, March 1992.

Linsky, J.L., "A-type and chemically peculiar stars," G.S. Vaiana Memorial Symposium: Advances in Stellar and Corona Physics, Palermo, Italy, June 1992.

Linsky, J.L., "GHRS observations of the local interstellar medium and the deuterium/hydrogen ratio along the line of sight towards Capella," ST-ECF/STScI Workshop on 'Science with the Hubble Space Telescope,' Chia Laguna, Italy, June 1992.

Linsky, J.L., "New stellar plasma density determinations by the GHRS: the transition regions of Capella and Gamma Draconis, ST-ECF/STScI Workshop on 'Science with the Hubble Space Telescope,' Chia Laguna, Italy, July 1992.

Linsky, J.L., "Radio and X-ray emission from chemically peculiar B- and A-type stars: observations and a model," IAU Colloquium No. 138, 'Peculiar versus Normal Phenomena in A-type and Related Stars,' Trieste, Italy, July 1992.

Linsky, J.L., "The search for primordial deuterium," Astronomy Department, Pennsylvania State University, University Park, PA, December 1992.

Nesbitt, D.J., "Walking up the potential energy surface: IR overtone spectroscopy of clusters," 39th Western Spectroscopy Association Conference, Asilomar, CA, January 1992.

Nesbitt, D.J., "Intramolecular vibrational energy flow in clusters: Hot dynamics in cold molecules," Department of Chemistry, Indiana University, Bloomington, IN, February 1992.

Nesbitt, D.J., "Intramolecular vibrational energy flow in clusters: Hot dynamics in cold molecules from high resolution infrared spectroscopy," Department of Chemistry, Purdue University, West Lafayette, IN, February 1992.

Nesbitt, D.J., "A reliable dipole moment function and state-to-state radiative rates for OH Meinel band emission," Climate Monitoring and Diagnostics Laboratory, Annual Meeting, Boulder, CO, March 1992.

Nesbitt, D.J., "Intramolecular forces through high resolution spectroscopy: From hydrogen bonds to micromatrices," 203rd American Chemical Society National Meeting, San Francisco, CA, April 1992.

Nesbitt, D.J., "It don't mean a thing if it ain't got that swing: Large amplitude motion in weakly bound complexes," Telluride Summer Workshop on Large Amplitude Motion, Telluride, CO, July 1992.

Nesbitt, D.J., "High resolution IR spectroscopy of Ar_n HX clusters: Orientational dependence of the micromatrix environment," Second Gordon Research Conference on Molecular and Ionic Clusters, Irsee, Germany, October 1992.

Nesbitt, D.J., "Intermolecular forces through high resolution IR spectroscopy of clusters and crossed beams," Department of Chemistry, Freie Universität, Berlin, Germany, October 1992.

Nesbitt, D.J., "Intermolecular forces through high resolution IR spectroscopy in clusters and crossed beams," Max Planck Institute for Stroemungsforschung, Goettingen, Germany, October 1992.

Nesbitt, D.J., "How molecules touch: Spectroscopic studies of intermolecular forces," Institute for Physical Chemistry, University of Basel, Basel, Switzerland, October 1992.

Nesbitt, D.J., "State-resolved energy transfer dynamics and intermolecular potentials: From clusters to crossed beams," Latsis Symposium 1992, ETH, Zurich, Switzerland, October 1992.

Nesbitt, D.J., "State-to-state collisional dynamics of atmospheric species," Molecular Dynamics Contractors Meeting, Washington, DC, October 1992.

Norcross, D.W., "Electron scattering from cesium: A fully relativistic treatment," Dept. of Physics, University of Missouri, Rolla, MO, November 1992. □

APPENDIX C

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

C

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

LABORATORY OFFICE

Chris E. Kuyatt

Secretary, International Electrotechnical Commission (IEC) Technical Committee (TC) 25: Quantities and Units and Their Letter Symbols), and TC 25, Working Group (WG) 1, Advisory and Preparatory.

Member, Advisory Panel to International Organization for Standardization (ISO) TC 12: Quantities, Units, Symbols, Conversion Factors.

Chairman, U.S. Technical Advisory Group (TAG) to ISO/TAG4: Metrology; member of ISO/TAG4 Working Group (WG) 3 Writing Group.

Member, Council for Optical Radiation Measurements (CORM).

Chairman, NIST Washington Editorial Review Board.

Chairman, NIST Radiation Safety Committee.

Member, Board of Editors, NIST Journal of Research.

Member, NIST Calibrations Advisory Group.

Member, Source Evaluation Board and Technical Review Panel of the NIST Advanced Technology Program.

William R. Ott

Member, Panel on Optics Technology Applications for the SDIO Technology Applications Office.

DoD Liaison, SDI-Related Metrology at NIST.

NIST Liaison, Society of Photo-Optical Instrumentation Engineers (SPIE).

Member, Program Committee for SPIE Conference, Ultraviolet Technology IV, July 1992.

Barry N. Taylor

Consultative Committee on Electricity and Consultative Committee on Units of the International Committee for Weights and Measures (CIPM).

Chair, American Physical Society Topical Group on Fundamental Constants and Precise Tests of Physical Laws.

CODATA Task Group on Fundamental Constants.

NIST Representative, Comptroller, and member of the Executive Committee of the Conference on Precision Electromagnetic Measurements (CPEM).

Board of Editors, *Metrologia*.

Technical Advisor to the U.S. National Committee of the International Electrotechnical Commission (IEC) on Technical Committee (TC) 25 Matters (TC 25: Quantities and Units and Their Letter Symbols), and member of TC 25, Working Group (WG) 1, Advisory and Preparatory.

U.S. Technical Advisory Group (TAG) for International Organization for Standardization (ISO)/ TC 12, Quantities, Units, Symbols, Conversion Factors, and International Advisory Panel to TC 12.

ISO TAG 4/WG 3, Expression of Uncertainties, and ISO TAG 4/WG 1, International Vocabulary for Metrology (TAG 4: Metrology).

NIST/CODATA liaison to the National Academy of Sciences/National Research Council Advisory Committee on Fundamental Constants and Standards.

Advisory Committee to the Particle Data Group, Lawrence Berkeley Laboratory.

Institute of Electrical and Electronics Engineers (IEEE) Standards Coordinating Committee 14, Quantities, Units and Letter Symbols.

Subcommittee on Standards and Metric Practice of the Metrication Operating Committee of the Interagency Committee on Metric Policy.

American Society for Testing and Materials Committee E-43 on SI Practice. □

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Robert J. Celotta

Member, American Physical Society Davisson-Germer Prize Committee.

Member, Advisory Committee, Conference on Magnetics and Magnetic Materials.

Charles W. Clark

Chair, Selection Committee, American Physical Society Award for Outstanding Doctoral Thesis Research in Atomic, Molecular, or Optical Physics.

Chair, Local Committee, Eighth U.S. National Synchrotron Radiation Instrumentation Conference.

Member, Collaborative Computational Project 2: Continuum States of Atoms and Molecules, Science and Engineering Research Council (UK).

Member, Virtual Reality Panel, Technical Support Working Group, U. S. Department of Defense.

Robert A. Dragoset

Subject Specialist, NIST Research Information Center.

Paul Lett

Member, Preliminary Design Review Committee for Project "Sunlite," NASA Langley Research Center.

Robert P. Madden

Member, Optical Society of America Ives Medal Committee.

Member, Optical Society of America R.W. Wood Prize Committee.

Member, Council of U.S. Synchrotron Radiation Laboratory Directors.

Member, International Committee of the International Conference on X-Ray and VUV Synchrotron Radiation Instrumentation.

Chair, Eighth U.S. National Synchrotron Radiation Instrumentation Conference.

Daniel T. Pierce

Co-Chair, Program Committee, American Physical Society Division of Materials Research Focused Session on Surface, Thin Films, and Multilayer Magnetism.

Member, International Organizing Committee, International Conference on Magnetic Films and Surfaces.

Member, NIST Research Advisory Committee.

Mark D. Stiles

Member, Program Committee, Fourth Workshop on Ballistic Electron Emission Microscopy.

Joseph A. Stroscio

Chair, Program Committee, Nanometer Science and Technology Division of the 40th National Symposium of the American Vacuum Society.

Member, Morton M. Traum Award Committee of the 39th National Symposium of the American Vacuum Society.

John Unguris

Member, Program Committee, International Conference on Magnetics and Magnetic Materials, Houston, TX. □

ATOMIC PHYSICS DIVISION (842)

Daniel E. Kelleher

Member, International Program Committee, International Conference on Spectral Line Shapes.

Yong-Ki Kim

Program Committee Member, American Physical Society Topical Conference on Atomic Processes in Plasmas (to be held in San Antonio, TX, in September 1993).

Program Committee Member, Nobel Symposium No. 85, held in Sweden, 29- June - 3 July 1992.

Program Review Committee Member, DOE Magnetic Fusion Program at Oak Ridge National Laboratory, 27-28 June 1992.

Secondary-Electron Spectra Report Committee Member, International Commission on Radiation Units, 1990-1994.

William C. Martin

Chairman, Working Group on Atomic Spectra, International Astronomical Union.

Member, IAEA Network of Atomic Data Centers for Fusion.

Peter J. Mohr

Member of Advisory Board of the Institute for Theoretical Atomic and Molecular Physics at Harvard University.

Contributor to the assessment of atomic, molecular, and optical sciences being carried out by the National Research Council Panel on the Future of Atomic, Molecular, and Optical Sciences.

William D. Phillips

Chairman, Atomic Physics Gordon Conference 1993.

Chairman, Optical Physics Group, Optical Society of America.

Member, OSA Technical Council.

Member, Joint Council on Quantum Electronics.

Member, Intl. Council on Quantum Electronics.

Member, Division of Atomic, Molec. and Opt. Physics Program Committee.

Member, Intl. Conf. on Laser Spec. Program Committee.

Arlene Robey

Equal Employment Opportunities Counselor, NIST Collateral Duty Assignment (Term Expired Early 1992).

Jack Sugar

Chairman, and Member, Organizing Committee for "Fourth International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas," held September 1992 at NIST.

Member, Committee to Review the Journal of the Optical Society B.

Wolfgang L. Wiese

President, Commission on Atomic and Molecular Data, International Astronomical Union.

Member of Organizing Committee, International Astronomical Union, Commission on Atomic and Molecular Data.

Chairman, Working Group on Atomic Transition Probabilities, International Astronomical Union.

Member, Network of Atomic Data Centers for Fusion, coordinated by the International Atomic Energy Agency (IAEA).

Member, Organizing Committee, 4th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas. □

MOLECULAR PHYSICS DIVISION (843)

Jon T. Hougen

Chairman, International Advisory Committee for the Ohio State Symposium on Molecular Spectroscopy, 1992.

Chairman, International Advisory Committee for the Prague Symposium on High Resolution Infrared Spectroscopy, 1992.

Marilyn E. Jacox

Member, AFOSR High Energy Density Materials Panel.

Member, DOE Research Evaluation Panel for Spectroscopy of Transient Molecules.

Chairman, Award Recognition Committee, NIST Chapter of Sigma Xi.

Chairman, Selection Committee for WISE Lifetime Achievement Award, Interagency Committee for Women in Science and Engineering.

Paul S. Julienne

Member, International Committee of the International Conference on the Physics of Electron and Atomic Collisions.

Co-Chairman, Symposium on Cold Atom Collisions at the Institute for Theoretical Atomic and Molecular Physics at the Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, April 1992.

Frank J. Lovas

Member, Working Group 5 (Molecular Spectral), Commission 14: Fundamental Spectroscopic Data, International Astronomical Union.

Alfons Weber

Chairman, Program Committee on Lasers in Chemistry and Biology, QELS'92 Quantum Electronics and Laser Science Conference, Anaheim, CA, May 1992.

Member, Council of the American Physics Society.

Chairman, Audit Committee, American Physics Society.

Member, Membership Committee, American Physical Society. ▫

RADIOMETRIC PHYSICS DIVISION (844)

Clara Asmail

Member, ASTM E-12 Committee, Appearance of Materials, Subcommittee E-12.09 on Scattering.

Yvonne Barnes

Member, ASTM E-12 Committee, Appearance of Materials, Subcommittees E-12.01 on Editorial and Terminology, E12.02 on Spectrophotometry and Colorimetry, E-12.03 on Geometric Properties.

Sally Bruce

Member, Electromechanical Systems Engineering Technology Advisory Committee, Montgomery College.

Christopher L. Cromer

Member, CORM Subcommittee CR-1 on Sources for Radiometry and Photometry.

Member, CORM Subcommittee CR-2 on Array Radiometry.

Co-chairman, SPIE Conference on Photodetectors and Power Meters.

Chairman, Session on Ground-Based Applications, Newrad 92 Conference.

Raju Datla

Member, Space-Based Observation Systems, Committee on Standards, American Institute of Aeronautics and Astronautics, Sensing Systems Working Group, Subcommittee on IR Systems.

Kenneth L. Eckerle

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittees E-13.01 on Ultraviolet and Visible Spectroscopy, E-13.03 on Infrared Spectroscopy, E-13.06 on Molecular Luminescence.

Member, CIE TC2-28 on Methods of Characterizing Spectrophotometers.

George P. Eppeldauer

Member, CORM Subcommittee CR-1 on Sources for Radiometry and Photometry.

Member, CORM Subcommittee CR-2 on Array Radiometry.

Member, CORM Subcommittee CR-3 on Photometry.

Laurance E. Fink

NIST Representative, ANSI IT2 on Image Evaluation and IT2.28 on Densitometry Standards.

Charles E. Gibson

Member, ASTM E-20 Committee, Temperature Measurements, Subcommittee E-20.2 on Radiation Thermometry.

Jonathan E. Hardis

Member, U.S. National Committee of the CIE.

Member, CORM.

Member, SPIE.

Jack J. Hsia

Associate Director, CIE Division 2, Physical Measurement of Light and Radiation.

Chairman, CIE TC 2-11 Technical Committee on Goniophotometry.

Secretary, U.S. National Committee of the CIE.

Member, ASTM E-12 Committee, Appearance of Materials, Subcommittees E-12.01 on Editorial and Terminology, E-12.02 on Spectrophotometry and Colorimetry, E-12.03 Geometric Properties, E-12.09 on Scattering.

Member, ASTM E-13 Committee, Molecular Spectroscopy; Subcommittees E-13.01, Ultraviolet and Visible Spectroscopy; E-13.03, Infrared Spectroscopy, and E-13.06, Molecular Luminescence.

Delegate, Inter Society Color Council.

NIST Alternate Representative, ANSI IT2 on Image Evaluation and IT2.28 on Densitometry Standards.

John K. Jackson

Member, CORM Subcommittee CR-1 on Sources for Radiometry and Photometry.

Thomas C. Larason

NIST Consultant, National Conference of Standards Laboratories; Subcommittee on Electro-Optical Metrology, National Measurement Requirements.

Yoshihiro Ohno

Member, Testing Procedure Committee of IESNA.

Chairman, CORM Subcommittee CR-3 on Photometry.

Chairman and Reporter, CIE Subcommittee R2-08 on Detector-based Photometry.

Member, U.S. National Committee of the CIE.

Member, CCPR Working group on V(lambda) Corrected Detectors.

Albert Parr

CORM Subcommittee CR-1 on Sources for Radiometry and Photometry.

Member, U.S. National Committee of the CIE.

CIE Division 2 Reporter, "Application of Cryogenic Radiometry."

NIST representative to CCPR and Member of Subcommittees on UV Standards and Radiometric Lamp Availability.

Ex Officio Member and NIST Liaison, CORM Board of Directors.

Planning Committee – SRI-93 Synchrotron Instrument Meeting.

Robert D. Saunders, Jr.

Member, ANSI Z311, Photobiological Safety of Lamps and Lighting Systems.

Member, CIE TC2-05, Definition and Measurement of Distribution Temperature.

Alternate, ASTM E-20, Temperature Measurements.

Alternate, ASTM E-44, Solar Energy Conversion.

Member, USNC/CIE.

Member, USDA Steering Committee for UV-B Measurements.

E. Ambler Thompson

Member, IES Photobiology Committee.

Secretary, CIE Division 6, Photobiology and Photochemistry.

Member, U.S. National Committee of the CIE.

Member, ASTM E13.06 on Molecular Luminescence.

James H. Walker

Member, CORM Subcommittee CR-1 on Sources for Radiometry and Photometry. ▫

QUANTUM METROLOGY DIVISION (845)

Richard D. Deslattes

Member, Executive Committee of the PRT/IDT Council for the National Synchrotron Light Source.

Member, University of Chicago Review Committee for Physics Division, Argonne National Laboratory.

Member, International Advisory Board, Journal Physics B, 1992 -.

Member, selection committee for SBIR proposals, NSF Physics Division.

Member, Department of Energy Ernest O. Lawrence Award, 1993 -.

Chairman, Nominating Committee, APS Topical Group on Fundamental Constants and Precision Tests of Physical Theory.

Chairman, Program Committee, U.S. National Synchrotron Radiation Instrumentation Conference, US SRI 8, 1993.

Member, Organizing Committee, International Nuclear Physics Conference, Wiesbaden, Germany, July 26 - August 1, 1992.

Member, International Committee Nobel Symposium on "Heavy Ion Spectroscopy and QED Effects in Atomic Systems," Stockholm, Sweden, June 29-July 3, 1992.

Chairman, International Workshop on Applications of High Resolution Gamma Spectroscopy in Studies of Atomic Collisions and Nuclear Lifetimes, Grenoble, France October 5-7, 1992.

Michael Danos

Member, Program Committee, NATO Advanced Study Institute, Pascoli, Italy, July 13-18, 1992. □

IONIZING RADIATION DIVISION (846)

Jacqueline M. Calhoun

Member, United States Council on Energy Awareness (USCEA), Subcommittee for USCEA/NIST Measurement Assurance Program for the Nuclear Medicine Industry.

Member, United States Council on Energy Awareness (USCEA), Subcommittee for USCEA/NIST Measurement Assurance Program for the Nuclear Power Industry.

Member, National Pharmaceutical Association.

Member, National Institute of Standards and Technology Day Care Scholarship Committee.

Allan D. Carlson

Chairman, Nuclear Energy Agency Nuclear Science Committee (NEANSC) International Inter-Laboratory Working Group on the $^{10}B(n,\alpha)$ Standard Cross Sections.

Chairman, Standards Subcommittee, Cross Section Evaluation Working Group (CSEWG).

Member, Evaluation Committee of CSEWG.

Member, Data Status and Requests Subcommittee of CSEWG.

Member, International Program Committee, International Conference on Nuclear Data for Science and Technology, to be held May 9-13, 1994 in Gatlinburg, TN.

Randall S. Caswell

Chairman, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), Office of Science and Technology Policy.

Alternate Member, Main Committee, CIRRPC.

Honorary Member, National Council on Radiation Protection and Measurements (NCRP).

Member and Secretary, International Commission on Radiation Units and Measurements (ICRU).

Sponsor, ICRU Report Committee on Stopping Power for Protons and Alpha Particles.

Sponsor, ICRU Report Committee on Stopping Power for Heavy Ions.

Sponsor, ICRU Report Committee on Absorbed Dose Standards for Photon Irradiation and Their Dissemination.

Sponsor, ICRU Report Committee on In-Situ Gamma-Ray Spectrometry in the Environment.

Sponsor, ICRU Report Committee on Beta-Ray Dosimetry for Radiation Protection.

Ronald Collé

Member, Interagency Committee on Indoor Air Quality (CIAQ), Radon Workshop.

Louis Costrell

Chairman, DoE National Instrumentation Methods (NIM) Committee.

Chairman, American National Standards Institute (ANSI) Committee N42, Radiation Instrumentation.

Member, ANSI Nuclear Standards Board.

Member, ANSI Nuclear Standards Board Planning Committee.

Secretary, Institute of Electrical and Electronic Engineers (IEEE) Nuclear Instrumentation and Detectors Committee.

Ex-Officio Member, IEEE Nuclear and Plasma Sciences Society Administrative Committee.

Chairman, IEEE Nuclear and Plasma Sciences Annual Meetings Committee.

Member, Organizing Committee, 1993 IEEE Particle Accelerator Conference.

Member, U.S. National Committee of the International Electrotechnical Commission (IEC).

Chief U.S. Delegate, IEC Committee TC45, Nuclear Instrumentation.

Chairman, IEC Committee TC45 Working Group 9, Detectors.

Bert M. Coursey

Alternate Commerce Delegate to Science Panel, Committee on Interagency Radiation Research and Policy Coordination, OSTP.

Consultant to Radiation Therapy Committee of American Association of Physicists in Medicine (AAPM).

Delegate to Section I (X-, Gamma-, and Electron- Radiations) of the Comité Consultatif pour les Étalons de Mesure des Rayonnements Ionisants.

Chairman, Techniques in Radionuclide Metrology Working Group, International Committee for Radionuclide Metrology.

Member American National Standards Institute Subcommittee N42.2 "ANSI Standards for Nuclear Radiation Detectors."

Member Technical Organizing Committee, 1993 Applications of Radionuclide Metrology International Conference, International Committee for Radionuclide Metrology.

Marc F. Desrosiers

Member, International Atomic Energy Agency (IAEA) Coordinated Research Program on "Alanine Dosimetry at the Radiation Therapy Level."

Chairman, ESR subcommittee, IAEA Coordinated Research Program on "Analytical Detection Methods for the Irradiated Treatment of Foods."

Program Chairman, Washington Electron Paramagnetic Resonance (EPR) Discussion Group.

Member, U.S. delegation, "International Consultative Group on Food Irradiation."

Co-Chairman, ASTM Committee E10.01F, Dosimetry for Radiation Processing/ Alanine standard.

NIST representative, FCCSET Committee on Food, Agricultural, and Forestry Research, Food Safety Research Workgroup.

Charles E. Dick

Member, Technical Organizing Committee, International Conference on the "Application of Accelerators in Research and Industry."

Member, Editorial Review Board of Industrial Metrology.

Charles M. Eisenhauer

NIST representative to Science Panel of Committee on Interagency Radiation Research and Policy Coordination (CIRRPC).

Member, NCRP.

David M. Gilliam

NIST representative to the Comité Consultatif pour les Étalons de Mesures des Rayonnements Ionisants, Section III - Mesures Neutroniques.

NIST liaison to the NCRP.

Geoffrey L. Greene

Member, Steering Committee for the Advanced Neutron Source (NSCANS) (member of NSCANS and NSCANS executive committee).

Consultant, Basic Energy Sciences Advisory Committee on Neutron Sources.

Member, National Science Foundation Review Panel on Small Nuclear Physics Facilities.

James A. Grundl

Member, NCRP Task Group SC-63 on Public Knowledge About Radiation Emergencies.

Member, CIRRPC Subpanel on Public Education.

Jimmy C. Humphreys

Co-chairman of task group developing a standard on "Statement of Uncertainties in Radiation Dosimetry," in ASTM subcommittee E10.01 on Radiation Processing Dosimetry.

J. M. Robin Hutchinson

Secretary, ANSI N42.2: "Radioactivity Measurements."

Member, International Committee for Radionuclide Metrology (ICRM), Executive Committee.

Member, International Committee of Weights and Measures (BIPM), Consultative Committee on Standards for Measuring Ionizing Radiations, Subcommittee Section II: Radionuclide Measurements.

Kenneth G. W. Inn

Member, ANSI N13.30, Quality Assurance for Radiobioassay.

Emmert D. McGarry

Member, ASTM Committee E10; Subcommittee E10.05, Nuclear Metrology.

Chairman, Awards Committee of ASTM Subcommittee E10.05.

Member, Planning Committee for the 9th ASTM-EURATOM Symposium on Reactor Dosimetry.

William L. McLaughlin

Technical Advisor, Council of Europe Parliamentary Assembly, Work Group on Aerospace Physiology, Medicine, and Radiation Measurement.

Technical Advisor, council of Europe Parliamentary Assembly, Work Group on Space Biophysics.

Member, R&D Associates Committee on Irradiated Food Products.

Member, IAEA Advisory Group on High Dose Measurement and Standardization for Radiation Processing.

Member, Association for the Advancement of Medical Instrumentation (AAMI) Subcommittee on Radiation Sterilization Dosimetry (Working Groups on Gamma Ray Sterilization and Electron Beam Sterilization).

Technical Advisor, NCRP Scientific Committee 63, Radiation Exposure Control in a Nuclear Emergency.

Chairman, IAEA Advisory Panel on Electron Beam Dosimetry for Industrial Radiation Processing.

Member, ASTM Committee E10, Subcommittee E10.01, Dosimetry for Radiation Processing.

Member, ASTM Committee E10, Subcommittee E10.07 on Ionizing Radiation Dosimetry and Radiation Effects on Materials and Devices.

Member, U.S. Subcommittee Technical Advisory Group (TAG) for International Standards Organization (ISO) Technical Committee (TC) 198 Working Group 2, Radiation Sterilization;

Member, U.S. Subcommittee TAG for ISO/TC 198, Working Group 2, Packaging.

Francis J. Schima

Member, IAEA Coordinated Research Program on Gamma-Ray Standards for Detector Calibration.

Member, ANSI Subcommittee N42.2 working group for the Standard: Calibration and Use of Germanium Detectors for the Measurement of Gamma-ray Emission Rates of Radionuclides.

Roald A. Schrack

Representative, Department of Commerce to Environmental Protection Agency Interagency Working Group on Residual Radioactivity of Federal Installations.

Robert B. Schwartz

Member, ISO/TC 85 (Nuclear Energy), Subcommittee 2 (Radiation Protection). Chairman, Neutron Working Group.

Stephen M. Seltzer

Member, ICRU Report Committee on Stopping Power.

Consultant, ICRU Report Committee on Material Equivalent and Tissue Substitutes.

Participant in the IAEA Coordinated Research Program on Atomic and Molecular Data for Radiotherapy.

Consultant, Lawrence Livermore National Laboratory (LLNL), to provide electron and positron interaction data for the LLNL Evaluated Nuclear Data Library (ENDL).

Christopher G. Soares

Member, Health Physics Scientific Subcommittee Work Group for the revision of ANSI N13.11, "Personnel dosimetry performance – Criteria for testing."

Member, Health Physics Scientific Subcommittee Work Group for the revision of ANSI N545, "Performance, testing, and procedural specifications for thermoluminescence dosimetry (environmental applications)" and the writing of ANSI N13.29, "Criteria for testing environmental dosimetry performance."

U.S. Technical expert appointed by ANSI to the International Standards Organization subgroup (ISO TC 85/2/2/0) for the revision of ISO 6980, "Reference beta radiations for calibrating dosemeters and doseratemeters and for determining their response as a function of beta radiation energy."

Member, Health Physics Scientific Subcommittee Work Group for the revision of ANSI N545, "Performance, testing, and procedural specifications for thermoluminescence dosimetry (environmental applications)" and the writing of ANSI N13.29, "Criteria for testing environmental dosimetry performance."

U.S. Technical expert appointed by ANSI to the ISO sub-group (TC 85/2/2/0) for the revision of ISO 6980, "Reference beta radiations for calibrating dosemeters and doseratemeters and for determining their response as a function of beta radiation energy."

Julian H. Sparrow

Co-Chairman, Component Inspection Standards group of the Joint-Army-Navy-Air Force (JANNAF) Nondestructive Evaluation Subcommittee.

Michael P. Unterweger

Member, ASTM D022 Committee on Sampling and Analysis of Atmospheres.

Member, DoE NIM Committee.

Member, ANSI N42.2, Radioactivity Measurements.

Member, IEEE Nuclear Instruments and Detectors Committee.

Marlon L. Walker

Member, National Organization for the Professional Advancement of Black Chemists and Chemical Engineers.

Member, National Society of Black Physicists.

Mary D. Walker

Member, Health Physics Society (HPS) Laboratory Accreditation Assessment Committee.

Member, Conference of Radiation Control Program Directors (CRCPD) Committee on Ionizing Radiation.

Oren A. Wasson

Member, Department of Energy Nuclear Data Committee.

Member, Data Measurement Subcommittee of CSEWG. □

TIME AND FREQUENCY DIVISION (847)

Roger E. Beehler

Chairman, U.S. Study Group 7A, Consultative Committee on International Radio.

John J. Bollinger

Member, NIST Research Advisory Committee.

Dick D. Davis

Member, Working Group on GPS Time Transfer Standards of the Consultative Committee on the Definition of the Second.

D. Wayne Hanson

Member, Working Group on Two-Way Satellite Time Transfer of the Consultative Committee on the Definition of the Second.

Leo Hollberg

Member, Scientific Review Committee for the NASA Sunlite Project.

James L. Jespersen

Chairman, Timing Committee, InterRange Instrumentaion Group.

Member, Telecommunication Subcommittee on Time and Synchronization.

George Kamas

Member, Measurement Assurance Subcommittee, National Conference of Standards Laboratories.

Judah Levine

Member, Working Group on International Atomic Time TAI of the Consultative Committee on the Definition of the Second.

Member, Working Group on GPS Time Transfer Standards of the Consultative Committee on the Definition of the Second.

Donald B. Sullivan

Member, Consultative Committee on the Definition of the Second.

Member, Commission A on Time and Frequency, International Union of Radio Science.

Member, Executive Committee for the Conference on Precision Electromagnetic Measurements.

Member, Executive Committee for the Annual IEEE Frequency Control Symposium.

Marc Weiss

Member, Working Group on International Atomic Time TAI of the Consultative Committee on the Definition of the Second.

Member, Working Group on GPS Time Transfer Standards of the Consultative Committee on the Definition of the Second.

Member, Telecommunication Subcommittee on Time and Synchronization.

David J. Wineland

Member, National Academy of Science

Chairman, APS Division of Atomic, Molecular and Optical Physics

Member, NIST Precision Measurement Grants Committee. □

QUANTUM PHYSICS DIVISION (848)

Peter L. Bender

Chairman, Science Team for the Lunar Interior Structure Mission concept, developed for the NASA Discovery Program.

Member, NASA Management and Operations Working Group for UV and Optical Astronomy and Relativity.

Member, Control/Structure Integration Program Advisory Committee, NASA.

Member, Lunar Laser Ranging Management and Operations Working Group.

Member, Committee of Fellows, American Geophysical Union.

Gordon H. Dunn

Chairperson, Committee on Atomic, Molecular and Optical Sciences (CAMOS) of the National Research Council.

Co-chairperson, panel on Future Opportunities in Atomic Molecular and Optical Sciences of the National Research Council.

Executive Committee, International Conference on the Physics of Electronic and Atomic Collisions (ICPEAC).

Member, Fellowship Committee of DAMOP.

Member, Panel on Public Affairs (POPA) of the American Physical Society.

Member, Program Committee, International Conference on the Physics of Highly Charged Ions.

James E. Faller

Advisory capacity to the Gravity Research Institute (GRI).

Member Lunar Laser Ranging Management and Operations Working Group.

Member, Working Group II of the International Gravity Commission.

Member, Special Study Group 3.87, "Development of Worldwide Absolute Gravity Net," of the International Gravity Commission.

Member, Directing Board, International Gravity Commission.

Representative to IAG Commission III International Gravity Commission.

John L. Hall

Delegate, Consultative Committee for the Definition of the Meter (BIPM), Sèvres, France.

Co-Chairman, International Steering Committee for Conferences on Laser Spectroscopy.

Member, NIST Committee for Precision Measurement Grants.

Member, AMO Subcommittee of Physics Division, Academy of Science.

Stephen R. Leone

Award Committees for the American Chemical Society and American Physical Society

Program Committee, Division of Atomic, Molecular and Optical Physics, American Physical Society.

Steering Committee, Laser Science Topical Group, American Physical Society.

Jeffrey L. Linsky

Chairperson, User's Committee, International Ultraviolet Explorer Satellite, NASA.

Chairman, Management Operations Working Group, Science Operations Branch, NASA.

Chairman, US Scientific and Technical Working Group for the Large Earth-Based Solar Telescope (LEST), High Altitude Observatory, NCAR.

Chairman, Final Archives Definition Committee for the IUE satellite data, NASA.

Co-chair, Scientific Organizing Committee for the G. S. Vaiana Memorial Symposium "Advances in Stellar and Solar Coronal Physics."

Member, Lyman Far Ultraviolet Spectrograph Explorer Phase B Science Team, NASA.

Member, IUE Long Range Planning Committee, NASA.

Member, Management Operations Working Group, UV Astronomy and Gravity Branch, NASA.

Member, Science Working Group for the Advanced X-ray Astrophysics Facility (AXAF), NASA.

Member, Science Working Group for the Space Telescope Imaging Spectrograph, NASA.

Member, Science Working Group, HST Goddard High Resolution Spectrograph, NASA.

Member, Observatories Visiting Committee, Association of Universities for Research in Astronomy (AURA).

Member, Scientific Organizing Committee for the Eighth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, Athens, GA.

Member, Scientific Organizing Committee for "Frontiers of Space- and Ground-based Astronomy," Noorwijk, Netherlands, 10-14 May 1993.

David J. Nesbitt

Organizer, 40^{th} Annual Western Spectroscopy Association Conference.

Co-chair, Gordon Conference "Atomic and Molecular Interactions."

David W. Norcross

Secretary, TAMOC, an informal group representing scientists in the theoretical atomic and optical physics community. ▫

APPENDIX D

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

D

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

LABORATORY OFFICE

W. R. Ott organized and chaired a two-day DoD/SDI program review of NIST advanced metrology projects, December 1992.

W. R. Ott is chairman and principal organizer of the biweekly NIST Staff Colloquium Series.

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

T. B. Lucatorto organized the "Workshop on At-Wavelength Testing of Soft X-ray Projection Optics," held on the NIST Gaithersburg campus on June 22, 1992. This workshop, co-sponsored by NIST and AT&T Bell Laboratories, and supported by funds from the Advanced Technology Program and the Microelectronics Technology Office of the Defense Research Projects Agency, attracted 35 participants, primarily from the precision optics and semiconductor industries. Its purpose was to investigate alternatives for testing the performance of normal-incidence optics that work in the soft x-ray-region of the spectrum (photon wavelengths of around 10 nm). Precision manufacturing of visible-region optics requires continuous optical testing at the operational wavelength during the fabrication process; at present, it seems to be prohibitively expensive and difficult to perform such "at-wavelength" testing during the fabrication of soft x-ray optics. Workshop participants reviewed current methods for at-wavelength testing of soft x-ray optics, discussed possibilities for testing at longer wavelengths, and developed recommendations for standard protocols and the directions of future work.

M. L. Furst organized the "Scheduling Meeting for the Users of the Radiometric Instrumentation Calibration Facility at SURF-II," on the NIST Gaithersburg campus on November 2, 1992. This meeting attracted about 25 participants, primarily NASA employees and contractors, to work out schedules for use of the BL-2 calibration beamline. Such a meeting is required because many of the calibrations are associated with specific space missions with inflexible launch dates.

ATOMIC PHYSICS DIVISION (842)

J. Sugar was Chairman of the Organizing Committee for the 4th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, which was organized and hosted by the Atomic Physics Division at NIST on September 14-17. There were 170 registered attendees, with 26% foreign participation. The purpose of these meetings is to bring together users and producers of atomic data to focus on the most critical data needs, and to encourage the providers of these data to make the necessary measurements and calculations with the required accuracy.

RADIOMETRIC PHYSICS DIVISION (844)

R.U. Datla organized the Third NIST Low Background IR Facility Workshop held at Space Dynamics Laboratory (SDL), Logan, UT, 1992.

J.J. Hsia organized the Technical Council and Executive Committee meetings for the United States National Committee (USNC) of CIE held in Washington, DC, March 1992.

J.J. Hsia organized the Annual conference for the USNC/CIE held in Scottsdale, AZ, October 1992.

A.C. Parr was on the organizing committee for the Newrad '92 Conference held in Baltimore, MD, October 1992.

A.C. Parr was on the organizing committee for the CORM Conference in Greenbelt, MD, May 1992.

R.D. Saunders was on the organizing committee for the Newrad '92 Conference held in Baltimore, MD, October 1992.

IONIZING RADIATION DIVISION (846)

B.M. Coursey and J.C. Humphreys organized a workshop held at NIST on March 6, 1992 to discuss the status of the National Voluntary Laboratory Accreditation Program (NVLAP) Personnel Radiation Dosimetry Program. Participants discussed the impact on the program of the proposed ANSI N13.11, American National Standard for Dosimetry–Criteria for Testing. The workshop was attended by representatives of the US Nuclear Regulatory Commission, DOE, members of the ANSI N13.11 standards writing committee, Battelle Pacific Northwest Laboratories, dosimetry processors, dosimetry users, and NVLAP technical experts.

K.G.W. Inn organized a workshop on "Standards for QA/QC" at the Conference on Low-level Measurements of Actinides and Long-lived Radionuclides in Biological and Environmental Samples, Rio de Janeiro, Brazil, October 1992. Leading international low-level radioactivity experts discussed three major areas: 1) bioassay, 2) environment, and 3) radionuclide speciation. The objectives of the workshop were to identify areas where new standards for quality assurance and control were needed, prioritize the lists of needed standards, and make recommendations to standards producing agencies. The conclusions reached at the workshop were that highest priorities should go to the production of standard phantoms for *in-vivo* radiobioassay measurements of people, homogeneous mixed waste soil, and plutonium +4 and +6 in solution for aquatic speciation studies.

M.D. Walker helped organize the "Workshop on CRCPD Secondary Calibration Laboratories," Sacramento, CA, September 1992. The workshop was organized to provide a forum for exchanging information and ideas useful for the continued operation and improvement of the Conference of Radiation Control Program Directors (CRCPD)-accredited laboratories. Mary also served on the CRCPD Committee on Ionizing Radiation (G-2) which met during this workshop. The committee agenda included discussion of a definition of traceability for submission to Part A of the State Suggested Regulations for Controlling Ionizing Radiation (SSRCR).

TIME AND FREQUENCY DIVISION (847)

D.A. Howe and P.J. Tomingas organized the "Time and Frequency Seminar," June 25-27, at NIST, Boulder, CO. This three-day tutorial seminar, which was attended by 45 people (maximum feasible attendance) from industry and government, included lectures by NIST and other invited experts covering the theory and application of time and frequency measurement and dissemination systems. This annual seminar provides the key U.S. means for training scientists and engineers in this field.

M.A. Weiss organized a special three-day "Workshop on Synchronization Standards for Telecommunications Systems" held at NIST in Boulder on August 3-5, 1992. A key objective of the workshop, which was attended by 43 representatives from industry, was to familiarize the industry with new, NIST-developed measures of system performance that have recently been adopted as standards by both the U.S. industry and the international telecommunications industry.

The Time and Frequency Division served as a sponsor of the 46th IEEE Frequency Control Symposium held in Hershey Pennsylvania on May 27-29, 1992. Members of the Division served on the Technical Program Committee, the Symposium Executive Committee, and the tutorial instruction staff for a one-day tutorial preceding the meeting. This is the key U.S. annual meeting in the area of time and frequency technology. □

APPENDIX E

JOURNAL EDITORSHIPS

E

JOURNAL EDITORSHIPS

LABORATORY OFFICE

Taylor, B.N., Chief Editor, *Journal of Research of the National Institute of Standards and Technology.*

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Celotta, R.J., Co-editor, *Methods of Experimental Physics*, Academic Press Series.

Clark, C.W., Topical Editor for Atomic Spectroscopy, *Journal of the Optical Society of America B*

Lucatorto, T.B., Co-editor, *Methods of Experimental Physics*, Academic Press Series.

ATOMIC PHYSICS DIVISION (842)

Fuhr, J.R., Editor, "Atomic Transition Probabilities," *Handbook of Chemistry and Physics*, CRC Press.

Reader, J., Editor, "Line Spectra of the Elements," *Handbook of Chemistry and Physics*, CRC Press.

Sansonetti, C.J., Topical Editor for Atomic Spectroscopy, *Journal of the Optical Society of America B.*

Sugar, J., Guest Editor, "Physica Scripta Topical Issue" for *Proceedings of Fourth International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas.*

Wiese, W.L., Associate Editor, *Journal of Quantitative Spectroscopy and Radiative Transfer.*

Wiese, W.L., Member, Editorial Advisory Board, *Spectrochimica Acta B (Atomic Spectroscopy)*, Pergamon Press.

Wiese, W.L., Editor, "Atomic Transition Probabilities," *Handbook of Chemistry and Physics*, CRC Press.

Wiese, W.L., Member, Editorial Board, "Supplement Series" to *Nuclear Fusion.*

MOLECULAR PHYSICS DIVISION (843)

Hougen, J.T., Member, Editorial Advisory Board, *Journal of Molecular Spectroscopy.*

Jacox, M.E., Member, Editorial Board, *Journal of Chemical Physics.*

Weber, A., Editorial Advisory Board, *Journal of Raman Spectroscopy.*

IONIZING RADIATION DIVISION (846)

Coursey, B.M., Editor, *Applied Radiation and Isotopes.*

Coursey, B.M., Editor, *Nuclear Medicine and Biology.*

Coursey, B.M., Editorial Board, *Radioactivity and Radiochemistry.*

Coursey, B.M., Guest Editor, *Nuclear Instruments and Methods in Physics Research, Part A*, "Proceedings of the International Symposium on Radionuclide Metrology and its Applications."

Desrosiers, M.F., Editor, "Proceedings of the Third International Symposium on ESR Dosimetry and Applications," *Applied Radiation and Isotopes* **44** (1-2) (1993).

Dick, C.E., Member, Editorial Board, *Industrial Metrology.*

McLaughlin, W.L., Editor in Chief, *Applied Radiation and Isotopes*, North America.

McLaughlin, W.L., Editorial Board, *Radiation Physics and Chemistry.*

QUANTUM PHYSICS DIVISION (848)

Dunn, G.H., Editorial Board, *Journal of Physical and Chemical Reference Data.*

Leone, S.R., Advisory Editorial Board, *Chemical Physics Letters.*

Leone, S.R., Editorial Board, *Progress in Reaction Kinetics.*

Leone, S.R., Associate Editor, *Annual Review of Physical Chemistry.*

Linsky, J.L., Associate Editor, *Newsletter of the American Astronomical Society.*

Linsky, J.L., Member, Editorial Board, *Solar Physics.* ▫

APPENDIX F

INDUSTRIAL INTERACTIONS

F

INDUSTRIAL INTERACTIONS

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

■ **Methods for Isotopically-Selective Ionization.** The Photon Physics Group works with Eastern Analytical, Inc., College Park, MD, under the auspices of a CRADA. Joint research is performed on multiphoton ionization of calcium, the goal being the optimization of methods for isotopically selective ionization. Such methods would be used to enrich stable, low-abundance isotopes of calcium, which are required for biomedical applications such as clinical studies of human nutrition. Eastern Analytical's portion of the work has been funded by venture capital and contracts with the National Institutes of Health and the Department of Energy. An Eastern Analytical employee works full time in the Photon Physics Group Laboratories.

■ **Optics for X-Ray Lithography.** The Photon Physics Group worked with Hampshire Instruments, Inc., Rochester, NY, under the auspices of a CRADA. This project involved the investigation of alternative schemes for collimating x rays from a point source (such as a laser-produced plasma) for applications to x-ray lithography of semiconductors.

ATOMIC PHYSICS DIVISION (842)

■ **Advanced Cs Atomic Clock Research.** The Laser Cooling and Trapped Atoms Group works with Rincon Research Corporation under the auspices of a CRADA. A collaboration has been established to work toward the development of an advanced cesium microwave frequency standard based on laser-cooled atoms. The advantage of laser-cooled atoms is their slow velocities, which allow extremely long interaction times. This will directly reduce the linewidth by as much as two orders of magnitude, and will reduce most of the systematic errors. Such a standard has the promise of vastly increased stability and accuracy over the current state-of-the-art standards.

RADIOMETRIC PHYSICS DIVISION (844)

■ **Haze Measurement.** J.J. Hsia had a CRADA with BYK-Gardner, Inc., Silver Spring, MD, for development of Haze measurement master standards important for the automobile windshield, plastic, and appearance industries.

■ **Luminescence Spectroscopy.** A.E. Thompson worked with Infrared Fiber Systems, Inc., Silver Spring, MD, under the auspices of a CRADA. The objectives of this research are the measurement of Didymium luminescent samples on the NIST Reference Spectrofluorimeter and the evaluation of their utility as luminescence standards for excitation and emission wavelength calibration.

■ **Radiometric Measurement Services for Industries.** The Radiometric Physics Division performed calibrations and provided standard reference materials for more than one hundred U.S. companies. These services are needed for measurements of spectral radiometry, pyrometry, photometry, detector metrology and spectrophotometry.

■ **High Internal Transmittance Glass.** K.L. Eckerle consulted with Corning Glass Company on high accuracy transmittance measurements for developing glass materials with a very high internal transmittance.

■ **Translucent Material Measurement.** J.J. Hsia provided consultation to Rohn and Haas Company on transmittance measurement methods of translucent material important to the plastic industry.

■ **Solar Cell Measurements.** J.K. Jackson worked with the Photovoltaic Device Measurement Laboratory (PDML) at Sandia National Laboratories on a measurement procedure to improve the accuracy of reference cell calibrations for solar measurements. The new procedure not only reduced the time necessary for calibration, but decreased by one half the uncertainty of the current ASTM procedure.

■ **Improved Quartz Halogen Lamp.** As members of the CR-1 committee on Sources for Radiometry and Photometry of CORM, R. D. Saunders, J. K. Jackson, and A. C. Parr have worked with

Bob Low of GTE Sylvania on characterizing prototypes and suggesting modifications to an improved 1000 watt quartz halogen lamp for use as spectral irradiance and luminous intensity standards.

■ **Temperature Controlled Silicon Radiometers.** G. Eppeldauer transferred the recently developed NIST radiometer fabrication technology to Eastman Kodak. The radiometers measure radiant power with a dynamic range of 14 decades. The Kodak prototypes have been fabricated. Kodak plans to fabricate many devices for use as calibrating standards and measuring devices in a variety of radiometric applications. The techniques for making temperature controlled photometers and colorimeters, suitable for detector-based illuminance and color calibrations, was made available to Kodak.

■ **Corrosion Monitoring.** A.L. Migdall is assisting XSirius Superconductivity, Inc. on the development of a reflectometer for use as a corrosion monitor. A FTIR spectrometer at NIST is being used to measure spectral reflectance of samples of materials at various levels of corrosion. The intention is to observe the signature of corrosion in the early stages and to develop a simple instrument to monitor corrosion as it develops. This should reduce the cost of determining corrosion times and to aid in development of higher corrosion resistance materials.

■ **Measurement Assurance for Retroreflector.** K.L. Eckerle is collaborating with industry on retroreflectance measurements. He assisted the completion of an ASTM test method for retroreflection. He is collaborating with 3M Company to investigate possible changes in cube corner retroreflectors. This should improve the measurement of retroreflectors which are important for highway safety.

■ **Transmission Density.** L.E. Fink is collaborating with Eastman Kodak Company on the transmission density scales. Recently, he has completed an intercomparison of photographic step tablets according to the ISO standard method with Kodak Company as well as PTB of Germany. The transmission density is the optical property used for quality control in printing, photographic, and imaging device industries.

■ **Bidirectional Scattering Metrology Round Robin.** C. Asmail is collaborating with Science Services, Inc. to conduct a round robin study of bidirectional reflectance distribution function (BRDF) measurement facilities. Four samples are being circulated through the United States for BRDF measurements in the infrared. The goals of this research are: to investigate variations between scatter facilities; to test the usefulness of a ultra-low scattering sample as a diagnostic standard; and to test the utility of the new ASTM BRDF Standard Practice.

■ **Ozone Monitoring.** The Radiometric Physics Division is assisting Ball Aerospace Inc., Boulder, CO, on the NASA project of Solar Backscatter Ultraviolet for monitoring ozone depletion. The following staff members are providing the assistance: (1) P. Y. Barnes and J. J. Hsia for diffuse reflectance and BRDF measurements of diffusers and (2) J. K. Jackson and R. D. Sanders for irradiance measurement of lamps.

■ **Spectrophotometer Improvement.** P.Y. Barnes, for five years, has been assisting Varian Inc., Analytical Instrument Division, Sunnyvale, CA, in improving UV-VIS-NIR spectrophotometer design and measurement methodology.

■ **Radiometric Calibration Improvement.** Staff members of the Radiometric Physics Division are assisting several industrial corporations to improve their radiometric measurements: (1) R.D. Saunders, C.L. Cromer, and B.C. Johnson assisting ITT Fort Wayne, LIRIS, and EG&G Judson for the Geosynchronous Orbiting Earth System program of NOAA; (2) B.C. Johnson and C.L. Cromer supporting the Ocean Color Community for the Sea Wide field of View sensor program of NASA; and (3) B.C. Johnson assisting TRW, Hughes Santa Barbara Research for the Earth Observation System program of NASA.

■ **SEMATECH.** NIST is working with SEMATECH, a consortium of U.S. semiconductor manufacturing companies, to develop a prototype spectroradiometer for in deep UV exposure measurements in photolithographic semiconductor manufacturing equipment. C.L. Cromer, J. Roberts, and J.M. Bridges have been involved in this work. NIST is also working with the equipment manufacturers to provide adequate measurement support for field calibration of the embedded spectroradiometers.

■ **Phillips Labs.** NIST is being funded to provide support to the Phillips laboratories for remote sensing instrumentation calibrations. Phillips laboratories are engaged in a variety of remote sensing projects including comprehensive instrumentation on airborne platforms for remote sensing of missile plumes. C.L. Cromer and staff of the Radiometric Physics Division are providing calibrated reference standards and recommendations on calibration methodologies.

■ **Graseby Optronics.** C.L. Cromer has developed new types of silicon photodiode trap detectors for use with the NIST high accuracy cryogenic radiometer. These trap detectors have very good stability, quantum efficiency, and spatial uniformity and are suitable for use as high accuracy detector standards. NIST has encouraged and aided Graseby Optronics in the commercialization of these types of standard trap detectors.

■ **American Holographics.** C.L. Cromer worked with the company to develop a new type of double UV spectrograph for spectroradiometric measurements in the deep UV. The spectrometer is very compact, has very low scattered light, and has holographically corrected gratings for use with silicon photodiode arrays detectors.

■ **ILC Technology.** C.L. Cromer has been working with J.M. Bridges in the Atomic Physics Division and the ILC Technology to develop a new type of UV arc lamp. J.M. Bridges has extensive experience in using UV wall stabilized argon arc lamps for use as UV irradiance standard sources. ILC will manufacture a new compact ceramic arc lamp, using argon instead of xenon as in the past. The lamp will produce large amounts of UV radiation with less visible and infrared radiation.

IONIZING RADIATION DIVISION (846)

■ **Industrial X-Ray Radiography Systems.** C.E. Dick and M.R. McClelland work with Rayex Corp., Gaithersburg, MD under the auspices of a CRADA. Joint research is being performed to develop an x-ray imaging system for one-sided computerized tomography (CT) for medical and industrial applications. At the present time, the x-ray detector assembly has been assembled and is ready for testing. Such systems are of unique value in situations where conventional computerized tomography applications are not feasible. In a related project, a new generation of high power x-ray tubes is in the design stage. These tubes have the potential of either higher output or extended lifetimes and will be designed as direct replacements for current x-ray tubes.

■ **Standards and Traceability of the Radiopharmaceutical Industry.** The Radioactivity Group works with the Radiopharmaceutical Industry to provide needed standards and traceability services to the industry under the auspices of a CRADA with the U.S. Council for Energy Awareness (USCEA), Washington, DC. Radiopharmaceuticals used foı radioassay and radiotherapy are prepared and submitted as calibrated materials or as blinds to the participating companies. Major manufacturing companies such as Dupont-NEN, Mallinkrodt, Bristol-Meyers-Squibb, and Medi-Physics are actively involved.

■ **Standards and Traceability of the Nuclear Power and Standards Suppliers.** The Radioactivity Group works under a CRADA with a group under the USCEA which combines the nuclear power industry and standards production laboratories to provide standards and traceability services. These sources are used in power plant monitoring of the waste, normal operations, environmental monitoring, etc. The group includes nuclear power plants and radioactivity standards production laboratories.

■ **Tomosynthetic Dental X-ray System.** C.E. Dick and J.H. Sparrow cooperate with the Bowman Gray School of Medicine, Wake Forest University, Winston-Salem, North Carolina in a program to develop a dental tomographic system. Such a system will mark a major improvement in the diagnosis and treatment of periodontal disease, the major cause of tooth loss in adults. Progress this year in the computer reconstruction algorithm permits the use of fiducial markers. This alleviates the requirement for mechanically controlling the radioscopic geometry or rapidly acquiring the images before the patient's motion voids the inspection sequence.

■ **Large Format Real-Time X-Ray Imagers.** C.E. Dick serves as the Contracting Officer's Technical Representative for a phase II SBIR granted to Nanoptics, Inc., Gainesville, FL. This project aims at the development of real-time x-ray imagers with active diameters of 10 cm and larger. Such imagers will be of immense value in a large variety of medical and industrial imaging tasks. The Phase I portion of the program has just been successfully completed and demonstrated the feasibility of producing plastic fibre optic tapers which can be drawn into tapered boules to couple the active x-ray detector with electronic imaging cameras. Research is presently underway to dope the fibers with x-ray sensitive materials to produce a scintillating fibre optic.

■ **Reference Dosimetry for Proton Beams in Radiation Therapy.** B.M. Coursey and others in the Radiation Interactions and Dosimetry Group are working with Dr. Sandra Zink at the National Cancer Institute in developing passive dosimetry systems based on alanine/EPR and radiochromic films, for use in intercomparing accelerator proton beams in Russian therapy centers with those at the Harvard Cyclotron and Loma Linda Hospital in California. The initial NIST measurements in Moscow resulted in a change in the dosimetry data.

■ **Radiochromic Film Development.** W.L. McLaughlin is in a long-term collaboration with the International Specialty Products Division of GAF Corporation, Wayne, NJ to develop a series of novel radiochromic films. During the past year, NIST papers on high-resolution dose mapping with these films have led to rapid expansion of their use for treatment planning dosimetry, clinical radiography, brachytherapy, teletherapy, and stereotactic neurosurgery.

■ **Development of Industrial EPR Instruments.** M.F. Desrosiers is assisting Micro-Now Instruments, Chicago, IL in developing EPR readers for alanine dosimeters produced at NIST. The collaboration has established an interactive feedback between dosimeter design and reader sensitivity requirements. Such low-cost readers will be used in on-line free-radical measurements in product and process quality assurance for irradiated materials.

■ **Electron Irradiation of Silicon Solar Cells.** C.E. Dick consults with A. Meulenberg of Comsat Laboratories, Clarksburg, MD in a program to investigate radiation damage effects on solar cells designed for space satellite applications. Electron beams with energies similar to those found in polar orbits are utilized to irradiate cells in a fraction of the time required by other techniques and in a few hours can simulate many months of flight time. Utilization of the electron accelerator coupled with dosimetry techniques allows accurate estimates of the doses received and the induced damage to conventional and experimental devices.

■ **Characterization of Photostimulable Phosphors for X-Ray Imaging.** C.E. Dick and M.R. McClelland are working with C. Poirot of Quantex Corp. of Gaithersburg, MD on a program to develop and characterize photostimulable phosphors for x-ray imagers. Such phosphors record the latent x-ray image in electron traps until interrogated by an IR laser. These imagers have been tested in the radiography of a 30-cm water valve typical of those found in electrical generating plants. Because of their large dynamic range these imagers have a tremendous advantage over the current techniques employed in this type of inspection. Potential cost savings in maintenance of electrical power plants run into millions of dollars per year.

■ **Dosimetry for Irradiated Blood Products.** W.L. McLaughlin is working with the American Red Cross Biomedical Research and Development Laboratory, in collaboration with the USFDA Blood Products Advisory Committee, to standardize the irradiation of blood and biological materials. The blood products are irradiated to kill certain pathogens, but too much radiation will destroy the useful components. Radiochromic films are being used to map the radiation field inside the blood irradiators, to allow them to validate the correct dose to the product. This will impact on blood irradiation in thousands of blood centers, hospital blood banks, and other transfusion service centers.

■ **New Radon Emanation Standards.** Development of the new and novel NIST radium-solution encapsulated standards for radon emanation has been completed by the Radioactivity Group, and will be available in 1993 as an SRM for radon measurement calibrations. As part of this work, continuing collaborations with several other laboratories, including those within the commercial radon industry, are also ongoing. The collaborations are intended to evaluate the capsules' performance and to develop calibration protocols for specific radon field-measurement applications. One of these collaborations is with Rad Elec, Inc. (REI), the sole manufacturer of electret ionization chamber radon monitors. This instrumentation is the most widely employed measurement technique in the United States for evaluating radon levels in buildings. A preliminary cooperative study with REI demonstrated the practicality and suitability of the encapsulated standards for providing a simple and readily available calibration for electret measurement applications. Additional studies leading to the widespread deployment of the standards in the radon industry are underway, and the program will soon be developed into a formalized cooperative research and development agreement (CRADA).

■ **Solid State Track Recorder (SSTR) R&D.** Ultralight mass determinations in the nanogram and picogram range for SSTR dosimeters is a cooperative research effort with the Westinghouse Industrial Technology Center directed by E.D. McGarry. The endpoint is a new neutron dosimeter concept that makes use of a fissile layer placed adjacent to a polymer material which becomes conducting as a result of implantation of energetic heavy ions from nuclear fission. The trend in the nuclear power industry is for increased use of SSTR dosimetry as well as a recognized need for new types of neutron dosimeters that provide a wider dynamic range, permanently recoverable response, and ease of application.

■ **LiF Chip Gamma Dosimeters.** This novel high-dose, passive gamma dosimeter developed by D. Gilliam works on the principle of optical absorbency at specific wave lengths. In situ performance trials are underway at the Davis-Besse nuclear power reactor in cooperation with Toledo Edison Co. Gamma-ray heating and coupling with thermal neutron intensities are important for understanding radiation damage to critical reactor structures.

■ **Power Reactor Industry Benchmark Irradiation.** Radiometric dosimeters including NIST-developed PUD detectors, SSTR's and other dosimeter techniques have been irradiated simultaneously in an operating power reactor. Backed by NIST neutron fluence standards, this interlaboratory effort is needed to validate the diverse methods of dosimetry methods proposed for industry use. This collaboration with the Babcock & Wilcox Lynchburg Research Center is under the direction of E.D. McGarry.

TIME AND FREQUENCY DIVISION (847)

■ **Ionospheric Measurement Receiver.** R. Davis and M. Weiss have collaborated with Atmospheric Instrumentation Research in transferring technology for a NIST developed ionospheric measurement GPS receiver. The receiver has applications in time transfer, geophysical measurements and research on the properties of the ionosphere. Further joint development of the receiver is continuing. This work has taken place under a CRADA.

■ **Rugged Frequency Discriminator Cavity.** F. Walls is collaborating with California Microwave Incorporated in the development of a lightweight, high-Q-factor cavity with good vibration and thermal stability characteristics. This project has applicability both within the military and certain demanding civilian systems. This work is taking place under a CRADA.

■ **Low Noise Microwave Reference.** F. Walls of the Time and Frequency Division and W. Phillips of the Atomic Physics Division are collaborating with Rincon Research Corporation in the development of a an atomic-fountain clock. F. Walls is working on the low-noise microwave reference needed for the clock. This research will ultimately lead to a new generation of atomic frequency standards. The work is taking place under a CRADA.

■ **High-Performance Diode Lasers.** L. Hollberg is collaborating with Spectra-Diode Corporation on the development of precision, tunable, diode-laser sources for a variety of measurement applications. This work is taking place under a newly signed CRADA.

■ **Synchronization Interface Standard.** M. Weiss and D. Allan have collaborated with a telecommunications industry group in the development of a Synchronization Interface Standard for Telecommunications Networks. NIST led the introduction of the standard which has now been adopted nationally and internationally. This standard eliminated a key problem in the specification of equipment for SONET, an advanced optical fiber network that is expected to experience sales at a level of hundreds of millions of dollars per year. The NIST involvement has been well appreciated by the industry, and the interaction has resulted in the definition of a wider range of synchronization issues that will require NIST support.

QUANTUM PHYSICS DIVISION (848)

■ **Frequency Stabilizer to Increase Laser Power.** J.L. Hall has teamed up with M. Zhu and M. Jefferson of IBM's Almaden Research Center in San Jose, California, in a two-year project to develop an improved design for an external laser stabilizer. In 1984, Hall designed a stabilizer that reduces frequency noise without requiring optical modification of the laser. Through this CRADA, Zhu, Hall and Jefferson hope to improve the design, looking to develop a prototype that eventually can be licensed. IBM may use the stabilizer on lasers that probe spectral hole-burning effects in rare-earth, ion-doped crystals. Other potential benefits include information storage applications, optical frequency standards using sharp resonances in special crystals, and ultrahigh resolution spectroscopy.

■ **Methods for Measuring Propagation Characteristics of Lasers.** L. Austin and T. Johnston of Coherent Inc. and J. L. Hall are collaborating in a CRADA intended to develop and test a well-defined methodology for measuring and characterizing beams emitted by practical sources. Lasers are being invented at new frequencies by optical parametric amplification, frequency summing, and frequency multiplication. These transformations use nonlinear crystals that have angular acceptances that depend on planar orientation. Austin, Johnston and Hall hope to make useful advances in nonlinear optical conversion efficiencies with the help of a newly-developed Coherent beam-propagation instrument.

■ **Absolute Gravity Instruments.** J.E. Faller is collaborating and consulting with AXIS Instruments Company of Boulder, CO, on the engineering design and construction of instruments for the absolute measurement of gravity. This is a technology transfer exercise in which these instruments are being engineered from designs based on the original research instruments developed at JILA. The first two commercially produced instruments have been manufactured by AXIS and delivered to NIST for testing, evaluation and ultimate delivery to the National Geodetic Survey of NOAA. They will be used in NOAA's Global Change Program.

■ **Gravity Sensor for Use in Natural Gas Boreholes.** J.E. Faller is working as a consultant to the Gas Research Institute on their program to develop a new generation of borehole gravity sensors. The potential of a variety of techniques is being considered, including the vibrating quartz beam, zero-length spring, and atomic interferometry. Faller has provided expertise on such issues as the impact on accuracy to be expected from scaling and the use of better clocks to help determine the ultimate noise floor of designs. These borehole instruments are intended for prospecting applications.

■ **Fundamental research in quantum optics.** H.J. Kimble of Cal. Tech. and J.L. Hall collaborated in wide-ranging research efforts while Hall was in residence for three months at Cal. Tech. as a Sherman Fairchild Distinguished Scholar. They worked in the areas of spectroscopy with squeezed light and amplitude noise reduction using the "twin photons" concept based on a low-loss Optical Parametric Oscillator. They also investigated the role of geometrical phase in a quantum system with coupling to a dissipative bath. □

APPENDIX G

OTHER AGENCY RESEARCH AND CONSULTING

G

OTHER AGENCY RESEARCH AND CONSULTING

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

L.R. Canfield assisted personnel at the Lawrence Livermore National Laboratory and the Los Alamos National laboratory in the characterization of several soft x-ray detectors used for plasma diagnostics by the Department of Energy.

L.R. Canfield advised personnel at the Goddard Space Flight Center on a proposed far ultraviolet detection space experiment for NASA.

L.R. Canfield consulted with Raj Korde of International Radiation Detectors on matters involving semiconductor photodiodes in the far ultraviolet, and the calibration of a far ultraviolet photometer.

L.R. Canfield consulted with H. Ogawa and D. Judge concerning narrow-bandpass detector systems for solar flux determinations in rocket flight experiments and on a proposal for a satellite solar flux experiment.

C.W. Clark and D.R. Mueller consulted with Neocera, Inc. and Xsirius, Inc. on fabrication of thin-film superconductors.

T.B. Lucatorto consulted with Hampshire Instruments on the design of an x-ray collimator.

T.B. Lucatorto and R.N. Watts consulted with the DARPA Microelectronic Technology Office on the possibility of various designs for x-ray collimators.

T.B. Lucatorto consulted with the Office of Health and Environmental Research, U. S. Department of Energy on various forms of optical microscopy for biological research.

R.P. Madden, at the request of the Director of the Earth Science and Applications Division of the Office of Space Science and Applications, NASA, is coordinating an international round-robin intercomparison of solar irradiance monitoring space experiments. The first and second rounds of this intercomparison have been completed and the third round has begun.

R.P. Madden consulted with the NASA Advisory Committee, November 11-13, 1992.

J.J. McClelland, R.E. Scholten and R.J. Celotta have experimentally studied the spin dependent collision between electrons and atoms for the Department of Energy.

J.A. Stroscio, D.T. Pierce, R.A. Dragoset, and R.J. Celotta have used scanning tunneling microscopy to study epitaxial growth and low dimensional electronic structure for the Office of Naval Research.

J. Unguris, D.T. Pierce and R.J. Celotta have used the SEMPA technique to study surface magnetism and magnetic exchange coupling for the Office of Naval Research.

ATOMIC PHYSICS DIVISION (842)

J. Bridges, research for NASA: Ultraviolet and vacuum ultraviolet radiometry for space qualified portable sources.

Y.-K. Kim, research for DOE: Calculations of ionization cross sections of fusion research interest.

W.C. Martin, research for NASA: Critical compilations of atomic spectroscopic data needed for space astrophysics.

W.C. Martin, research for NASA: Building of an atomic spectroscopic database needed for space astronomy.

W.D. Phillips, research for NRL: Laser cooling and trapping of neutral atoms.

W.D. Phillips, research for ONR: Laser cooling and trapping of neutral atoms.

J. Reader, research for DOE: Spectroscopy of highly ionized atoms to obtain data needed for diagnostics of magnetic-fusion plasmas.

J. Reader, research for NASA: Wavelengths and isotope shifts for Hg III.

J. Roberts, research for SEMATECH: Ultraviolet irradiance measurement technology for SVGL Microscan photolithography systems.

J. Sugar, research for DOE: Critical compilation of atomic spectroscopic data of magnetic-fusion interest.

W.L. Wiese, (Principal Investigator), research for the Fusion Energy Office, DOE: Determination of atomic data for the fusion energy program. This is a 5-component program, covering experimental and theoretical work on spectroscopy and collision physics in the Atomic Physics Division and at JILA.

W.L. Wiese, research for NASA: Critical evaluation and compilation of transition probability data pertinent to the space astronomy program.

W.L. Wiese, research for NASA: A comprehensive spectroscopic database for astronomy.

W.L. Wiese, research for NASA: Far ultraviolet radiometric calibrations of solar physics experiments.

MOLECULAR PHYSICS DIVISION (843)

M.P. Casassa, D.S. King, and J.C. Stephenson, research for AFOSR: High Energy Density Materials Program: Ultraviolet laser photolysis studies of cluster molecules like O_3•H_2O.

J.T. Hougen, research for DOE: "Spectroscopic Investigation of the Vibrational Quasi-Continuum Arising from Internal Rotation of a Methyl Group."

M.E. Jacox, research for ARO: Spectroscopic Study of Reaction Intermediates and Mechanisms in Nitramine Decomposition and Combustion.

P.S. Julienne, research for ONR: Theory of Collisions of Laser-Cooled Atoms, in conjunction with the experimental NIST program in this area.

D.S. King, S.A. Buntin, R.R. Cavanagh, and L.J. Richter, research for DOE: State-Resolved Studies of Optically Driven Processes at Metal and Semi-Conductor Surfaces.

W.J. Lafferty, research for NASA: High Resolution IR Spectroscopic Studies on Atmospheric Molecules.

W.J. Lafferty, research for AFOSR: Studies Q-Branch Narrowing in Perpendicular Bands of CO_2.

F.J. Lovas and R.D. Suenram, research for ARO: Thermal Decomposition Pathways in Nitramine Propellants.

A.S. Pine research for NASA: Collisional Line-shapes and Molecular Beam Spectroscopy of Atmospheric Molecules. Line-broadening, line-mixing and Dicke narrowing studies of small atmospheric species; low-temperature, sub-Doppler spectroscopy of hydrochlorofluorocarbons and other heavy molecular species in a molecular beam.

RADIOMETRIC PHYSICS DIVISION (844)

C.C. Asmail, J.E. Proctor, and J.J. Hsia, research for the U.S. Air Force: Establishing bidirectional scattering measurement capability, methodology and developing standards.

P.Y. Barnes and J.J. Hsia, research for NASA: Providing diffuser calibration services for the two ozone monitoring projects: Shuttle Solar Backscatter Ultraviolet and Solar Backscatter Ultraviolet.

S.S. Bruce and B.C. Johnson, research for Newark Air Force Base: Development of a set of primary melting point blackbodies from 200 ^{0}C to 1000 ^{o}C.

S.S.Bruce and B.C.Johnson, research for Army Primary Laboratories: Development of primary Optical Temperature Standards.

R.J. Bruening and B.C. Johnson, research for the U.S. Navy Calibration Coordination Group (CCG): Establishing the capability for evaluating imaging infrared systems.

C.L. Cromer and J.E. Hardis, research for SEMATECH: Development of a prototype UV Spectroradiometer for semiconductor photolithography.

C.L. Cromer, research for the SDI Office: Extending detector based radiometry to the ultraviolet region of the spectrum.

C.L. Cromer and J.M. Houston, research for the U.S. Air Force CCG: Development of transfer standard detectors for use with the HACR.

C.L. Cromer and R.D. Saunders, research for the SDI Office: Evaluating the Argus Program calibration facilities and procedures.

C.L. Cromer, G. Eppeldauer, J.E. Hardis, and Y. Ohno, research for the U.S. Air Force CCG: Development of sources, detectors, and procedures to allow CCG laboratories to better utilize the new NIST methods of detector-based photometry.

R.U. Datla and S.R. Lorentz, research for U.S. Army SDIO: Low background infrared calibration and research.

R.U. Datla and S.R. Lorentz, research for the U.S. Air Force CCG: Providing experimental basis for the calculations of diffraction corrections in the cryogenic blackbody radiometry.

R.U. Datla and C.L. Cromer, research for the U.S. Air Force CCG: Development of ambient background infrared detector characterization facility.

K.L. Eckerle, research for the U.S. Air Force CCG: Development of infrared transmittance and specular reflectance measurement capability and standards.

G.E. Eppeldauer, C.L. Cromer, J.E. Hardis, and J. Fowler, research for Army Primary Labs: Supplying high-accuracy radiometer to the Army Primary Labs in Huntsville, AL.

L. Hanssen and J.J. Hsia, Collaboration with Naval Research Laboratory, with support from the U.S. NAVY CCG: Developing infrared diffuse reflectance measurement capability and standards.

B.C. Johnson and C.L. Cromer, research for NASA/GSFC: Supporting the calibration program for the SeaWifs program.

B.C. Johnson, research for NASA/GSFC: Supporting the Earth Observation System program.

R.D. Saunders and C.L. Cromer, research for the U.S. Navy CCG: Defining calibration technique and developing the standards required to support improved spectral radiometric power measurements for the Navy CASS Electro-optics Calibration System.

R.D. Saunders, C.L. Cromer, and B.C. Johnson, research for NOAA: Investigating the radiometric calibration procedures of the Geosynchronous Orbiting Earth System program.

A.E. Thompson and J.H. Walker, research for USDA: Development of a UV-B monitoring network for the United States.

A.E. Thompson and J.H. Walker, research for EPA: Development of a high accuracy spectroradiometer for the UV-B.

IONIZING RADIATION DIVISION (846)

R.S. Caswell and L.R. Karam, research for the Department of Energy: Calculations of the alpha-particle spectra and energy deposition spectra at the cells at risk in the bronchial epithelium from radon daughters deposited in the bronchial airways.

R.S. Caswell and S.M. Seltzer, research for the Department of Energy: Calculations of the energy deposition from neutrons in nanometer- and micrometer-size volumes aimed at understanding the biological effects of high-linear energy transfer (LET) particles such as neutrons and alpha particles.

L. Costrell, study for the Department of Energy: Needs and development of instrumentation and bus systems for data acquisition and control for nuclear particle and radiation physics.

M.F. Desrosiers and coworkers, with support from the Department of Defense: Developing electron spin resonance (ESR) techniques for post-irradiation measurements of free-radical centers in bone samples. The studies are focussing on hardware and software developments to lower the sensitivity and develop an analytical method.

M.F. Desrosiers, collaborations with the Department of Energy: ESR measurements of tooth enamel from victims of the Chernobyl accident. ESR tooth dosimetry has been used for the Hiroshima victims, and it is expected that with newer, more sensitive techniques it play an important role in the long-term monitoring of those exposed to radiation at the Chernobyl accident.

M.F. Desrosiers, collaborations with U.S. Army Aberdeen Proving Grounds, with support from the Environmental Protection Agency: Measurements of shell samples from estuaries around nuclear facilities. The electron spin resonance technique will be applied to measure the radiation-induced signal in shell samples.

C.M. Eisenhauer with collaborators from the Neutron Interactions and Dosimetry Group and Radiation Interactions and Dosimetry Group, consulting and measurement assurance for DoD/AFRRI: Microdosimetry measurements and determination of neutron kerma parameters for biological experiments carried out at Training, Research, and Isotope, General Atomics (TRIGA) reactor irradiation facility.

C.M. Eisenhauer and Robert B. Schwartz, consultation for the Defense Nuclear Agency (DNA): Experimental program at Aberdeen Proving Ground and tests of rotating spectrometer (ROSPEC) neutron spectrometer at NIST.

D. Gilliam, research for DOE: Study of neutron transport in water spheres with a fission neutron source to establish a benchmark for criticality safety calculations.

J.M.R. Hutchinson and collaborators in the Analytical Mass Spectrometry Group, Franklin & Marshall College, and Eastern Analytical Company: Installation of a glow-discharge source in one of the NIST RIMS machines. The ultimate purpose is to assay environmental radioactivity either in the original matrix or with minimum chemical steps being performed before being measured.

P.J. Lamperti and D.L. Bensen, collaborations with Federal Emergency Management Administration (FEMA): Measurement quality assurance studies and new instrument characterization for emergency radiation monitoring devices.

E.D. McGarry and J.A. Grundl, research and consulting for the Nuclear Regulatory Commission: Selective evaluation of neutron dosimetry results from metallurgical test irradiators, power reactor environments and benchmark experiments in support of surveillance dosimetry for light water reactor structures and components.

R.B. Schwartz and E.W. Boswell, facility design assistance for the U.S. Army: Suggest design parameters and capability options for a proposed Cf neutron calibration facility at the Redstone Arsenal installation.

S.M. Seltzer and M. Berger, proton-transport calculations for the National Cancer Institute (NCI): Aid NCI investigators in the interpretation of the biological effects of high-energy protons used in cancer therapy.

S.M. Seltzer, electron-transport calculations for the Department of Energy: The ETRAN code is used in calculating microdosimetric quantities of interest for radiation effects studies in medical sciences and health physics.

S.M. Seltzer, electron-transport calculations for NASA with support from their radiation health program: A Monte Carlo program is being developed to allow prediction of dose to space personnel for a given incident electron spectrum.

J.H. Sparrow, assists Navy and contractor personnel: Continuing review of the measurement aspects of the Navy quality assurance for radiographic inspections of large missile motors using linear accelerators. This includes on-site equipment calibration and verification and monitoring of radiographic image quality.

J.H. Sparrow and C.E. Dick, collaborations with the National Institute for Dental Research and the Bowman Gray School of Medicine: Development of a real-time computed tomographic (CT) system in which eight digital images are acquired of the same tooth from different incident x-ray angles, and a CT image is constructed.

M.D. Walker, collaborations with the Center for Devices and Radiological Health (CDRH) of the FDA: Spectral measurements for diagnostic x-rays. The CDRH and the states must ensure the compliance of all diagnostic x-ray machines with specifications for exposure and spectrum quality.

M.L. Walker, design work for the U.S. Army Redstone Arsenal: Remote real-time radiation dosimetry system based on laser readout of radiochromic film dosimeters.

O.A. Wasson, A.D. Carlson, and R.A. Schrack, neutron cross section standards and instrumentation for the DOE: provide accurate neutron interaction measurements for U.S. nuclear programs, including fission, fusion, safeguards, waste, and personnel protection. Further activities in this long-term program involve critical evaluation of neutron interaction data and data testing.

J.T. Weaver and P.J. Lamperti, collaborations with Navy personnel from the Naval Surface Warfare Center: Measurement quality assurance studies and new instrument characterization for Navy radiac instruments and TLD dosimeters.

TIME AND FREQUENCY DIVISION (847)

R.E. Beehler, consulting to National Weather Service, NOAA: Broadcast of marine weather alerts on WWV and WWVH.

R.E. Beehler, consulting to Coast Guard, DoT: Broadcast of status of GPS satellites on WWV and WWVH.

D.D. Davis, research and development for the U.S. Coast Guard: Synchronization for the LORAN-C navigation system.

R.E. Drullinger, research for Space Division, Air Force: Basic research on the physics of atomic standards.

K.M. Evenson, research for Astrophysics Laboratory, NASA: Far infrared spectroscopy for atmospheric and space studies.

L. Hollberg, research for Office of Space Science, NASA: Molecular frequency calibration standards and tunable laser spectroscopy.

F.L. Walls, research for Metrology and Calibration Division, Army: Development of measurement methods for phase noise.

F.L. Walls, research for Fort Monmouth, Army: Development of phase noise artifacts as transfer standards.

F.L. Walls, research for Guidance and Metrology Center, Air Force: Development of phase noise measurement system for Air Force.

M.A. Weiss, research and consulting for Space Division, Air Force: Analysis of GPS data and systems and consultation on operations.

M.A. Weiss, consulting to Jet Propulsion Laboratory, NASA: Time transfer to NASA sites, and analysis of time transfer data.

D.J. Wineland, research for Office of Naval Research: Frequency standards and basic studies with cooled, trapped ions.

D.J. Wineland, research for Office of Naval Research: Strongly-coupled, one-component plasmas stored in electromagnetic traps.

QUANTUM PHYSICS DIVISION (848)

P.L. Bender, research for NASA: Regional translocation analysis: comparison of LAGEOS II and LAGEOS I results.

P.L. Bender, research for NASA: Preliminary mission studies for a laser gravitational wave observatory in space.

P.L. Bender, research for NSF: Low frequency isolation systems for gravitational wave interferometers.

E. Cornell, research for NSF (GG)*: Research in atomic and molecular physics.

G.H. Dunn, research for DOE: Determine atomic, molecular, and nuclear data pertinent to the magnetic fusion energy program.

G.H. Dunn, research for NSF (GG)*: Research in atomic and molecular physics.

J.E. Faller, research for DMA: Absolute gravity meter development.

J.E. Faller, research for DMA-N: Absolute "g" co-op program.

J.E. Faller, research for GRI: Instrumentation for borehole gravity measurements.

J.E. Faller, research for NSF: Low frequency isolation systems for gravitational wave interferometers.

J.E. Faller, research for NGS: Absolute gravity meter development and repair/maintenance.

A. Gallagher, research for NOAA: CVD processes.

A. Gallagher, research for NREL: Growth mechanisms and characterization of hydrogenated amorphous silicon alloy films.

A. Gallagher, research for NSF (GG)*: Research in atomic and molecular physics.

J.L. Hall, consulting to an Advisory Committee to the Global Oscillation Network Group, National Solar Laboratory.

J.L. Hall, consultant on a Panel on laser Interferometric gravity wave detection of the National Science Foundation.

J.L. Hall, research for AFOSR: Optical frequency standards; Hertz-level working standards and their absolute frequency measurements.

J.L. Hall, research for NSF (GG)*: Research in atomic and molecular physics.

J.L. Hall, research for ONR: Precision atomic-beam spectroscopy with stabilized lasers.

S. Leone, research for AFOSR: Diode laser probing.

S. Leone, research for AFOSR: Laser probing of the kinetics and dynamics of III-V semiconductor growth.

S. Leone, research for AFOSR: Theoretical/experimental investigations of the structure and dynamics of highly energetic dication species.

S. Leone, research for AFOSR: State-resolved dynamics of ion-molecule collisions in a flowing afterglow.

S. Leone, research for AFPL: Optically pumped infrared lasers.

S. Leone, research for ARO: Surface deposition and etching interactions of laser-generated translationally hot atoms and radicals.

S. Leone, research for DOE: Time-resolved FTIR emission studies of laser photofragmentation and radical reactions.

S. Leone, research for NASA: Laboratory studies of low temperature rate coefficients: The atmospheric chemistry of the outer planets.

S. Leone, research for NASA: Laboratory infrared emission studies of interstellar molecules: polycyclic aromatic hydrocarbons and related species.

S. Leone, research for NSF: State resolved molecular dynamics.

S. Leone, research for NSF (GG)*: Research in atomic and molecular physics.

J.L. Linsky, consulting to the National Optical Astronomy Observatory (NOAO) and to the Association of Universities for Research in Astronomy (AURA) concerning operation of NOAO.

J.L. Linsky, research for NASA: Infrared, submillimeter and radio astronomy.

J.L. Linsky, research for NASA: studies of stellar chromospheres, winds, and the deuterium abundance of the Universe using the Hubble Space telescope (HST) (5 individual grants).

J.L. Linsky, research for NASA: Instrument Definition Team for the Space Telescope Imaging Spectrograph.

J.L. Linsky, research for NASA: Interdisciplinary Scientist for the Advanced X-ray Astrophysics Facility (AXAF).

J.L. Linsky, research for NASA: Studies of stellar coronae, winds, and magnetic activity using the International Ultraviolet Explorer (IUE) satellite (6 individual grants).

J.L. Linsky, research for NASA: Studies of X-ray emission from stellar coronae using the ROSAT satellite (6 individual grants).

J.L. Linsky, research for NASA: Analysis of HRTS spectra of Lyman alpha during a flare and an Ellerman bomb.

J.L. Linsky, research for NASA: Atmospheric diagnostics and modeling for stellar chromospheres and coronae.

J.L. Linsky, research for NASA: Studies of the extreme ultraviolet emission from stellar coronae with the Extreme Ultraviolet Explorer (EUVE) satellite (2 individual grants).

J.L. Linsky, research for NASA: Diagnostics of the hydrogen Lyman and Balmer lines during the impulsive phases of solar flares.

J.L. Linsky, research for NSF: U.S.–Australia cooperative research on stellar radio emission.

D. Nesbitt, research for AFOSR: Direct absorption laser studies of spectroscopy, kinetics and state-to-state collisional dynamics of atmospheric IR emitters.

D. Nesbitt, research for NATO: Theoretical studies of intermolecular potentials from IR van der Waals spectroscopy.

D. Nesbitt, research for NSF: Direct IR laser and double resonance absorption spectroscopy in slit supersonic jets: vibrational dynamics of novel molecular clusters.

D. Nesbitt, research for NSF (GG)*: Research in atomic and molecular physics.

D. Norcross, research for DOE: Electron impact excitation of atomic ions.

D. Norcross, research for NSF (GG)*: Research in atomic and molecular physics.

D. Norcross, research for NSF: Theoretical atomic, molecular and optical physics.

*NSF Group Grant: Atomic and Molecular Physics and Related Areas at the Joint Institute for Laboratory Astrophysics. ▫

APPENDIX H

CALIBRATION SERVICES AND STANDARD REFERENCE MATERIALS

H

CALIBRATION SERVICES AND STANDARD REFERENCE MATERIALS

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

CALIBRATION SERVICES PERFORMED

TYPE OF SERVICE	Customer Type*	SP 250 Item No.	No. of Tests or Calibrations
Far UV radiometric transfer standard detectors (photodiode calibrations)	1, 4-8	40510C 40511C 40520C 40531C 40560C 40561C 40599S	25
Spectrometer calibration using SURF-II as an absolute source	5-7	N/A	18
Totals			43

*Column 2:
1: calibration laboratories
2: hospitals
3: nuclear energy establishments
4: industry
5: U.S. government laboratories
6: DoD labs
7: universities
8: foreign governments

ATOMIC PHYSICS DIVISION (842)

CALIBRATION SERVICES PERFORMED

TYPE OF SERVICE	Customer	SP 250	No. of Tests	Income
Argon Arc	Holonix Corp.	40020C	1	3.5K
Argon Arc	Ball Aerospace		2	5.2K
Argon Arc	Nederlands Meetinstitüt	40040S	1	2.7K
Arc Lamp	Goddard Space Flight Center	40040S	2	3.5K
Deuterium Lamp	Goddard Space Flight Center	40040S	1	3.5K

RADIOMETRIC PHYSICS DIVISION (844)

CALIBRATION SERVICES PERFORMED

TYPE OF SERVICE	Customer	SP250	Number of Customers	Number of Tests*	Div. Income
Pyrometry		35010C thru 35070S	29	45	$ 61K
Industry					
Defense & Aerospace	9				
Instrument & Cal labs	4				
Electrical & Materials	10				
Government	5				
University	1				
Spectroradiometry - Sources		39010C thru 39060S	10	16	$ 43K
Industry					
Defense & Aerospace	1				
Instrument & Cal labs	2				
Lighting & Photography	1				
Electrical & Materials	1				
Government	5				
Spectroradiometry - Detectors		39070C thru 39080S	31	55	$ 72K
Industry					
Defense & Aerospace	6				
Instrument & Cal labs	10				
Lighting & Photography	7				
Government	8				
Photometry		37010C thru 37180S	7	17	$ 14K
Industry					
Defense & Aerospace	2				
Instrument & Cal labs	3				
Lighting & Photography	1				
Government	1				
Spectrophotometry		38010C thru 38100S	24	27	$ 39K
Industry					
Instrument & Cal labs	6				
Lighting & Photography	4				
Electrical & Materials	13				
Government	1				
			105	161	$ 229K

*Number of lamps, detectors, optical filters or reflectors tested.

RADIOMETRIC PHYSICS DIVISION (844) (Cont'd)

STANDARD REFERENCE MATERIALS

1. **SRM 1001**, X-Ray Film Step Tablet

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for transmission densities from 0 to 4.

2. **SRM 1008**, Photographic Step Tablets

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for transmission densities from 0 to 4.

3. **SRM 2015 and 2016**, White Opal Glass for directional-Hemispherical Reflectance from 400 to 750 nm.

   For use in calibrating the reflectance scale of integrating sphere reflectometers.

4. **SRM 2003**, First Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.

   SRM 2011, First Surface Gold Mirror for Specular Reflectance from 600 to 2500 nm.

   SRM 2023, Second Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.

   For use in calibrating the photometric scale of specular reflectometers.

5. **SRM 2009**, Didymium-Oxide Glass, Wavelength Standards between 400 and 760 nm.

   For use in calibrating the wavelength scale of scanning spectrophotometers.

6. **SRM 1920**, Near Infrared Reflectance Wavelength Standards from 740-2000 nm.

   For use in calibrating the wavelength scale of reflectance spectrophotometers.

7. **SRM 1931**, Fluorescence Emission Standards for the Visible Region.

   For use in calibrating the relative spectral response of fluorescence spectrometers.

IONIZING RADIATION DIVISION (846)

Office of Radiation Measurement

MEASUREMENT QUALITY ASSURANCE SERVICES – 1992

Accrediting Organization	Laboratory Tested	Fee
Conference of Radiation Control Program Directors	Illinois California	$2,000 $2,000
U.S. Dept. of Energy – DOELAP	Radiological and Environmental Sciences Laboratory, Idaho	$1,725
Health Physics Society	Eberline, New Mexico	$1,725
National Voluntary Laboratory Accreditation Program (Personnel Dosimetry)	Battelle Pacific Northwest Laboratories, Washington	$1,725
National Voluntary Laboratory Accreditation Program (Secondary Calibration Labs. for Ionizing Radiation)	Center for Devices and Radiological Health (USFDA), Maryland	$1,725

IONIZING RADIATION DIVISION (846) (Cont'd)

Radiation Interactions and Dosimetry Group

DOSIMETRY INSTRUMENT AND SOURCE CALIBRATIONS, FY 1992

	Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
1	Industrial	A	8	30	40,050
		B	19	66	44,370
		D	5	9	12,925
		F	6	10	24,380
2	Government Agencies	A	3	60	52,745
		C	1	2	2,070
		D	1	3	1,725
3	Dept. of Defense	A	6	95	102,735
		B	4	14	9,280
4	Medical Facilities	A	4	4	5,605
		C	2	2	2,070
		E	35	107	27,885
		F	14	14	18,445
5	Secondary Laboratories	A	2	13	13,205
		D	2	9	2,000
				0	
6	Universities	A	1	4	6,540
	SUBTOTALS:	A	24	206	220,880
		B	23	80	53,650
		C	3	4	4,140
		D	8	21	16,650
		E	35	107	27,885
		F	20	24	42,825
	GRAND TOTALS:	**ABCDEF**	**113**	**442**	**366,030**

Service Code	Type of Service	SP250 Number
A	X-Ray and Gamma-Ray Measuring Instruments	49010C
B	Dosimeter Irradiations	49020C & 49030C
C	Special Tests – Precision Electrometers	49040S & 49050S
D	Special Tests	46050S
E	Dosimetry of High Energy Electron Beams (Fricke Dosimetry)	48010M & 48011M
F	Gamma-Ray and Beta Particle Sources	47030C

IONIZING RADIATION DIVISION (846) (Cont'd)

Radiation Interactions and Dosimetry Group

HIGH-DOSE CALIBRATION SERVICES PERFORMED FY 1992

	Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
1	Industrial:	A	25	208	82,450
	medical product	B	3	4	5,717
	sterilization	C	0	0	0
2	Industrial:	A	0	0	0
	electronic	B	1	2	1,532
	hardness testing	C	0	0	0
3	Industrial:	A	0	0	0
	polymer	B	0	0	0
	modification	C	0	0	0
4	National Laboratory:	A	1	1	440
	electronic	B	1	1	1,433
	hardness testing	C	0	0	0
5	Dept. of Defense:	A	0	0	0
	electronic	B	1	12	6,128
	hardness testing	C	0	0	0
6	Secondary	A	0	0	0
	Calibration	B	0	0	0
	Laboratory	C	1	1	1,500
7	University:	A	1	8	3,455
	research	B	0	0	0
		C	0	0	0
	SUBTOTALS:	A	27	217	86,345
		B	6	19	14,810
		C	1	0	1,500
	GRAND TOTALS:	**ABC**	**34**	**236**	**102,655**

Service Code	Type of Service	SP250 Number
A	Irradiate Dosimeters	49010C
B	Supply Transfer Dosimeters	49020C & 49030C
C	Special Measurements	49040S & 49050S

IONIZING RADIATION DIVISION (846) (Cont'd)

Neutron Interactions and Dosimetry Group

CALIBRATION SERVICES PERFORMED

NEUTRON DOSIMETRY

Type of Service	Customer	SP250	No. of Tests
Neutron Protection Instrumentation	AFRRI	N/A	1
	Bartell Nuclear	44060C	4
	Calvert Cliffs	44060C	9
	Duquesne Light	44060C	4
	Eastman Kodak	44060C	1
	Eberline Inst. Co.	44060C	1
	EG&G	44060C	3
	Energy Operations	44060C	1
	Far West Technology	44060C	10
	Illinois Power	44060C	2
	IRT Corp.	44060C	1
	Mexico	N/A	2
	Redstone Arsenal	44060C	12
		Total	51
Neutron Source Calibration	EG&G Idaho	44010C	1
	Frontier Technology	44010C	1
	Oak Ridge Nat'l. Lab.	44010C	2
	Sandia National Lab.	44010C	3
	Three Mile Island	44010C	1
	University of Alabama	44010C	2
	University of Arkansas	44010C	3
	University of Michigan	44010C	1
		Sub Total	14
	In-house (NIST) Sources	N/A	4
		Total	18

IONIZING RADIATION DIVISION (846) (Cont'd)

Radioactivity Group

RADIOACTIVITY CALIBRATIONS

January 1, 1992 to December 31, 1992

CATEGORY	Scheduled Calibrations Number of Sources	Scheduled Calibrations Total Fee $	Non-Scheduled Tests Number of Sources	Non-Scheduled Tests Total Fee $
Alpha-particle Sources SP-250* Nos. 43030C	13	12,098	4	37,500
Beta-Particle Solutions and Gases (^{85}Kr)	——	——	5	16,600
Gamma-ray Solutions and Point Sources	5	6,075	11	18,973
Totals	18	18,173	20	73,073

*SP-250 numbers refer to scheduled calibrations

IONIZING RADIATION DIVISION (846) (Cont'd)

Radioactivity Group

STANDARD REFERENCE MATERIALS

Radioactivity Standards Issued - FY 1992

SRM	Radionuclide	Principal Calibration Use
4417L-L	Indium-111	Activity measurement of radio-pharmaceuticals
4406L-M	Phosphorus-32	"
4410H-R	Technetium-99m	"
4407L-Q	Iodine-25	"
4401L-R	Iodine-131	"
4412L-Q	Molybdenum-99	"
4415L-P	Xenon-133	"
4416L-M	Gallium-67	"
4404L-O	Thallium-201	"
4400L-N	Chromium-51	"
4321B	Natural Uranium	Tracer for radiochemical analysis
4322B	Americium-241	"
4332C	Americium-243	"
4334D	Plutonium-242	"
4952C	Radium-226 Blank	Radon analysis
4965	Radium-226	"
4966	Radium-226	"
4967	Radium-226	"
4201C	Niobium-94	Gamma-ray spectrometry analysis
4325	Beryllium-10/9	Tandem accelerator mass spectrometry
4990C	Oxalic Acid	Carbon dating

Total Radioactivity SRMs distributed: 769
Gross Sales: $342,482

TIME AND FREQUENCY DIVISION (847)

CALIBRATION SERVICES PERFORMED

Note that traceability to NIST and most calibrations are accomplished through direct uscr reception of NIST broadcasts from WWV, WWVB, WWVH, GOES, and ACTS. In general, for time and frequency metrology, it is only in special situations where in-house calibrations can achieve results not easily obtainable by signal transfer to the user.

FREQUENCY MEASUREMENT SERVICE	
This reimbursable service provides measurement assurance for calibration labs. NIST equipment at the user's lab receives LF signals as reference. Performance of user's equipment is monitored through a modem by NIST. An initial setup fee and a monthly fee are charged to the user. The total service income for FY 1992 was $226,400.	
Industrial Users:	36
Government Users:	18

GLOBAL TIME SERVICE	
This reimbursable service provides extremely high-accuracy reference to UTC(NIST) using the Common-View GPS Technique. NIST accesses data from the user's receiver, analyzes it, and provides a monthly report on the performance of the user's standard. An annual fee is charged to the user. The total service income for FY 1992 was $69,600.	
Industrial Users:	4
Scientific Users:	2
Foreign Users:	2

APPENDIX J

ACRONYMS

J

ACRONYMS

AAMI	Association for the Advancement of Medical Instrumentation
AAPM	American Association of Physicists in Medicine
ACR	Absolute Cryogenic Radiometer
ACTS	Automated Computer Time Service
ADCL	Accredited Dosimetry Calibration Laboratories
ADMIT	Analytical Detection Methods for the Irradiation Treatment of foods
AFB	Air Force Base
AFGL	Air Force Geophysics Laboratory
AFOSR	Air Force Office of Scientific Research
AFPL	Air Force Phillips Laboratory
AFRRI	Armed Forces Radiobiology Research Institute
AI	Associative Ionization
AIP	American Institute of Physics
AMO	Atomic, Molecular and Optical
ANS	American Nuclear Society
ANSI	American National Standards Institute
ANVIS	Aviator Night Vision Imaging System
APAS	Astrophysical, Planetary and Atmospheric Sciences
APOMA	American Precision Optics Manufacturers Association
APS	American Physical Society
APT	Annular Proton Telescope
ARO	Army Research Office
ARPES	Angle Resolved Photoelectron Spectroscopy
ASSI	Airglow Solar Spectrometer Instrument
ASTER	Advance Spaceborne Thermal Emission and Reflectance Radiometer
ASTM	American Society for Testing and Materials
AT&T	Atlantic Telephone & Telegraph
ATD	Above Threshold Dissociation
ATI	Above-Threshold Ionization
ATLAS	ATmospheric Laboratory for Applications and Science
AURA	Association of Universities for Research in Astronomy
AXAF	Advanced X-ray Astrophysical Facility
BARC	Bhabha Atomic Research Centre
BB	Blackbody
BBIR	Broad Band Infra Red
BBO	Beta-Barium Borate
BBXRT	Broad-Band X-Ray Telescope
BCS	Bardeen-Cooper-Schrieffer theory of superconductivity
BCS	Bragg Crystal Spectrometer
BEEM	Ballistic Electron Emission Spectroscopy
BFRL	Building & Fire Research Laboratory
BIB	Blocked Impurity Band
BIPM	Bureau International des Poids et Mesures
BL	Beam Line at SURF-II
BNL	Brookhaven National Laboratory
BRDF	Bidirectional Reflectance Distribution Function
BFR	Building & Fire Research Laboratory

BSDF	Bidirectional Scattering Distribution Function
BTI	Bubble Technology, Inc.
CAMOS	Committee on Atomic, Molecular and Optical Sciences
CARB	Center for Advanced Research in Biotechnology
CAST	Council of Agricultural Science and Technology
CBNM	Central Bureau for Nuclear Measurements
CCD	Charged Coupled Device
CCDM	Consultative Committee for the Definition of the Meter
CCE	Consultative Committee on Electricity
CCEMRI	Consultative Committee for Ionizing Radiations, CIPM
CCG	Calibration Coordination Group
CCPR	Consultative Committee on Photometry and Radiometry
CDRH	Center for Devices and Radiological Health
CEL	Correlated Emission Laser
CFS	Constant-Final-State Spectroscopy
CIAQ	Committee on Indoor Air Quality
CIE	Commission Internationale De L'Eclairage
CIPM	International Committee of Weights and Measures
CIRMS	Council on Ionizing Radiation Measurements and Standards
CIRRPC	Committee on Interagency Radiation Research and Policy Coordination
CIS	Constant-Initial-State Spectroscopy
CNRF	Cold Neutron Research Facility
CODATA	Committee on Data for Science and Technology
CORM	Council for Optical Radiation Measurements
COSPAR	Committee on Space Research
CPU	Central Processing Unit
CRCPD	Conference of Radiation Control Program Directors
CRADA	Cooperative Research and Development Agreement
CSDA	Continuous Slowing-Down Approximation
CSEWG	Cross Section Evaluation Working Group
CSI	Compton Scatter Imaging
CSIC	Consejo Superior de Investigaciones Cientificas
CSTL	Chemical Science and Technology Laboratory
CT	Computed Tomographic
CU	Colorado University
CVD	Chemical Vapor Deposition
DARPA	Defense Advanced Research Project Agency
DEC	Digital Electronics Corporation
DMA	Defense Mapping Agency
DNA	Defense Nuclear Agency
DNA	Deoxyribose Nucleic Acid
DoC	Department of Commerce
DOD (DoD)	Department of Defense
DOE	Department of Energy
DORT	Discrete Ordinates Code
DRIP	Detector Response Intercomparison Program
EBIS	Electron Beam Ion Source
EBIT	Electron Beam Ion Trap
ECP	Effective Core Potential
ECR	Electron Cyclotron Resonance
ECRIS	Electron-Cyclotron-Resonance Ion Source
ECS	Energy-Corrected-Sudden
EDX	Energy-Dispersive X-ray Analysis

EEEL	Electronics & Electrical Engineering Laboratory
EELS	Electron Energy Loss Spectroscopy
EEP	Einstein Equivalence Principle
EM	Environmental Management
ENDF	Evaluated Nuclear Data File
ENDL	Evaluated Nuclear Data Library
ENSDF	Evaluated Nuclear Structure Data File
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPR	Electron Paramagnetic Resonance
ERATO	Exploratory Research for Advanced Technology Office
EROS	Electric Resonance Optothermal Spectrometer
ESDIAD	Electron-Stimulated Desorption Ion Angular Distributions
ESR	Electron Spin Resonance (EPR now preferred)
ESR	Electrical Substitution Radiometer
ESR	Experimental Storage Ring
ETRAN	Computer Code
EUVE	Extreme Ultraviolet Explorer
FAA	Federal Aviation Administration
FAD	FASCAL Accurate Detector
FASCAL	Facility for Automatic Spectroradiometric Calibrations
FCCSET	Federal Coordinating Council Science, Engineering and Technology
FCDC	Fundamental Constants Data Center
FCPM	Fundamental Constants and Precision Measurements
FDA	Food and Drug Administration
FEL	Free Electron Laser
FEMA	Federal Emergency Management Agency
FET	Field Effect Transistor
FIMS	Fissionable Isotope Mass Standards
FIR	Far Infra Red
FIR	Far Infrared
FLIR	Forward Looking Infrared Radiometer
FNR	Ford Nuclear Reactor
FOS	Faint Object Spectrograph
FT	Fourier Transform
FT-IRAS	Fourier Transform-Infrared Reflection Absorption Spectroscopy
FTIR	Fourier Transform Infrared
FTS	Fourier Transform Spectroscopy
FUSE	Far Ultraviolet Spectroscopic Explorer
FUV	Far Ultraviolet
FWHM	Full Width at Half Maximum
FY	Fiscal Year
GAMS 4	NIST High Resolution Spectrometer
GBq	Gigabecquerels
GE	General Electric
GIM	Grazing-Incidence Monochromator
GINGA	Japanese X-ray Satellite
GHRS	Goddard High Resolution Spectrograph
GOES	Geostationary Operational Environmental Satellite
GPIB	General Purpose Instrumentation Bus
GPS	Global Positioning System
GRT	Germanium Resistance Thermometers
GSI	Gesselschaft für Schwerionenforschung

H	Hungary
HACR	High Accuracy Cryogenic Radiometer
HDR	High Dose Rate
HFIR	High Flux Isotope Reactor
HPS	Health Physics Society
HRTS	High Resolution Telescope Spectrograph
HSST	Heavy Section Steel Technology
HST	Hubble Space Telescope
HTS	High-Temperature Superconductivity
HUT	Hopkins Ultraviolet Telescope
HVL	Half-Value Layer
IAEA	International Atomic Energy Agency
IAG	International Association of Gravity
IAU	International Astronomical Union
IBM	International Business Machines
IC	Integrated Circuit
ICPEAC	International Conference on the Physics of Electronic and Atomic Collisions
ICRM	International Committee for Radionuclide Metrology
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGC	International Gravity Commission
ILL	Institut Laue Langevin
ILS	International Laser Spectroscopy
IMS	Institute for Molecular Science
INM	Institute National de Metrologie
INMM	Institute for Nuclear Materials Management
INSPIRE	Interactive NASA Space Physics Ionospheric Radio Experiment
INTERNET	An International Computer Network
IPSN	Institut de Protection et de Sureté Nucleairé
IPTS	International Practical Temperature Scale
IQEC	International Quantum Electronics Conference
IR	Infrared
IRAS	Infrared Reflection Absorption Spectroscopy
ISCC	Inter-Society Color Council
ISO	International Organization for Standardization
ITEP	Institute for Theoretical and Experimental Physics
ITER	International Thermonuclear Experimental Reactor
ITS	International Temperature Scale
IUCr	International Union of Crystallography
IUE	International Ultraviolet Explorer
IVR	Intramolecular Vibrational Relaxation
IVR	Intramolecular Vibrational Redistribution
JAERI	Japan Atomic Energy Research Institute
JANNAF	Joint-Army-Navy-Air Force
JET	Joint European Torus
JILA	Joint Institute Laboratory for Astrophysics
JPL	Jet Propulsion Laboratory
LAGOS	Laser Gravitational-Wave Observatory in Space
LAMPF	Los Alamos Meson Physics Facility
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Scattering Center
LASP	Laboratory for Atmospheric and Space Physics, University of Colorado

LBIR	Low Background Infrared Radiometry
LBL	Lawrence Berkeley Laboratory
LBRS	Low Background Reference System
LEED	Low Energy Electron Diffraction
LEI	Laser-Enhanced Ionization
LET	Linear Energy Transfer
LIF	Laser Induced Fluorescence
LIGO	Laser Interferometric Gravitational-Wave Observatory
LLNL	Lawrence Livermore National Laboratory
LMR	Laser Magnetic Resonance
LORAN-C	A Radio Navigation System Operated by the U.S. Coast Guard
LS	Liquid Scintillation
LTE	Local Thermodynamic Equilibrium
MARS	Multiple-Angle Reference System
MBE	Molecular Beam Epitaxy
MBOS	Molecular-Beam Optothermal Spectrometer
MCNP	Monte Carlo Neutron Photon (computer code)
MCQDT	Multi Channel Quantum Defect Theory
MCU	Mobile Calibration Unit
MDRF	Materials Dosimetry Reference Facility
MEA	Materials Engineering Associates
MEL	Manufacturing Engineering Laboratory
MET	Medium Energy Telescope
MIDAS	Modular Interactive Data Acquisition System
MIM	Metal-Insulator-Metal (Diode)
MIRD	Medical Internal Radiation Dose (committee)
MIRF	Medical and Industrial Radiation Facility
MIT	Massachusetts Institute of Technology
MODIL	Manufacturing Operations Development & Integration Laboratory
MODIS	Moderate Resolution Imaging Spectrometer
MOKE	Magneto-Optical Kerr Effect
MOPITT	Measurement of Pollution In The Troposphere
MPI	Multiphoton Ionization
MQA	Measurement Quality Assurance
MRI	Magnetic Resonance Imaging
MRT	Minimal Resolvable Temperature
MSEL	Materials Science and Engineering Laboratory
MSX	Midcourse Space Experiment
MTG	Methanol To Gasoline
MURR	University of Missouri Research Reactor
MW	Microwave
NAS	National Academy of Sciences
NAS/NRC	National Academy of Sciences/National Research Council
NASA	National Aeronautic and Space Administration
NATO	North Atlantic Treaty Organization
NBS	National Bureau of Standards
NBS-4	Older Primary Frequency Standard (retains NBS name)
NBS-6	Current Primary Frequency Standard (retains NBS name)
NCAR	National Center for Atmospheric Research
NCI	National Cancer Institute
NCRP	National Council on Radiation Protection and Measurements
ND	Neutron Density
NDT	Nondestructive Testing
NEANSC	Nuclear Energy Agency Nuclear Science Committee

NED	Nuclear Effects Directorate
NIM	Normal-Incidence Monochromator
NIM	National Instrumentation Methods
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NIST-7	Next Primary Frequency Standard
NML	National Measurement Laboratory (Japan)
NMR	Nuclear Magnetic Resonance
NOAA	National Oceanographic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NOBCChE	National Organization for the Professional Advancement of Black Chemists and Chemical Engineers
NORA	Non-Overlapping Redundant Array
NPL	National Physical Laboratory (U. K.)
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NRC	National Research Council (Canada)
NREL	National Renewable Energy Laboratory
NRL	Naval Research Laboratory
NRRS	Near Resonance Rayleigh Scattering
NSBP	National Society of Black Physicists
NSCANS	National Steering Committee for the Advanced Neutron Source
NSF	National Science Foundation
NSLS	National Synchrotron Light Source, Brookhaven National Laboratory
NVIS	Night Vision Imaging System
NVLAP	National Voluntary Laboratory Accreditation Program
OMEGA	24 Beam Laser Facility at Rochester
ONR	Office of Naval Research
OPO	Optical Parametric Oscillator
OPTCON	International conference sponsored by 3 agencies: Optical Society of America; Society of Photo-optical Instrumentation Engineers; and Institute of Electrical and Electronics Engineers
ORM	Office of Radiation Measurement
ORELA	Oak Ridge Electron Linear Accelerator
ORNL	Oak Ridge National Laboratory
OSA	Optical Society of America
OSRD	Office of Standard Reference Data
OSTP	Office of Science and Technology Policy
PA	Proton Affinity
PC	Personal Computer
PFID	Perturbed Free Induction Decay
PL	Physics Laboratory
PMG	Precision Measurement Grant
PMS	Particle Measurement System
PNL	Pacific Northwest Laboratory
POPA	Panel on Public Affairs
PRL	Physical Review Letters
PRM	Precision Radiation Measurement
PSD	Photon-Stimulated Desorption
PTB	Physikalisch-Technische Bundesanstalt (Germany)
PTFE	Polytetrafluoroethylene
PUDS	Paired Uranium Detectors
PWR	Pressurized-Water Reactor
PWS	Primary Working Standards

QCD	Quantum Chromo Dynamics
QED	Quantum Electro Dynamics
QELS	Quantum Electronics and Laser Science
QFT	Quantum Field Theory
QMD	Quantum Metrology Division
QPD	Quantum Physics Division
R&D	Research & Development
RBE	Relative Biological Efficiency
REDA	Resonant-Excitation-Double-Autoionization
RBS	Rutherford Backscattering
RF	Radio-Frequency
RHEED	Reflection High Energy Electron Diffraction
RIMS	Resonance Ionization Mass Spectrometry
RKR	Rydberg-Klein-Rees
ROSAT	Roentgensatellit Satellite
ROSPEC	Rotating Spectrometer for Neutrons
RS-232	An IEEE Standard Bus
SBIR	Small Business Innovation Research
SCC	Standards Coordinating Committee
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SEAWIFS	Sea-Viewing of Wide Field Sensor
SEBA	Standards' Employees Benefit Association
SEM	Scanning Electron Microscope
SEMATECH	Consortium of 14 U.S. Semiconductor Manufacturers
SEMPA	Scanning Electron Microscopy with Polarization Analysis
SFCP	Special Foreign Currency Program
SFG	Sum Frequency Generation
SI	International System of Units
SKACR	Superconducting Kinetic-inductance Absolute Cryogenic Radiometer
SOLSPEC	Solar Spectrometer
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPIE	Society of Photo-optical Instrumentation Engineers
SRM	Standard Reference Material
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSPM	Solid State Photomultipliers
SSRCR	State Suggested Regulations for Controlling Ionizing Radiations
SSTR	Solid State Track Recorder
SSUV	Shuttle Solar Ultraviolet
STM	Scanning Tunneling Microscope
STM	Scanning Tunneling Microscopy
STScI	Space Telescope Science Institute
SUNY	State University of New York
SURF	Synchrotron Ultraviolet Radiation Facility
SURF-II	The NIST Synchrotron Ultraviolet Radiation Facility Electron Storage Ring
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
TAG	Technical Advisory Group
TAI	International Atomic Time
TAMOC	Theoretical Atomic, Molecular, and Optical Physics Community
TC	Technical Committee
TCAP	Time-Correlated Associated Particle
TEPC	Tissue Equivalent Proportional Counter
TEXT	Texas Experimental Tokamak

TGM	Toroidal-Grating Monochromator
TLD	Thermoluminescent Detector
TOF	Time-of-Flight Spectrometer
TOMS	Total Ozone Mapping Spectrometer
TPD	Temperature Programmed Desorption
TQM	Total Quality Management
TRIGA	Training, Research and Isotope Reactor, General Atomics
TuFIR	Tunable Far Infrared (Radiation)
UARS	Upper Atmosphere Research Satellite
UDC	University of the District of Columbia
UHV	Ultra High Vacuum
UK	United Kingdom
UPS	Ultraviolet Photoelectron Spectroscopy
US	United States
USA	United States of America
USAIDR	U.S. Army Institute of Dental Research
USCEA	U.S. Council for Energy Awareness
USDA	United States Department of Agriculture
USNA	U.S. Naval Academy
USNO	U.S. Naval Observatory
USSR	Union of Soviet Socialist Republics
UTC	Coordinated Universal Time
UV	Ultraviolet
UV-B	Ultraviolet-B
VEEL	Vibrational and Electronic Energy Levels
VET	Vibration Energy Transfer
VIS	Visible
VLA	Very Large Array
VLBI	Very Long Baseline Interferometer
VLBI	Very-Long-Baseline Interferometry
VNIIM	Mendeleyev Institute of Metrology
VNIIOF	All-Union Research Institute for Optical and Physical Measurements
VUV	Vacuum Ultraviolet
WAFAC	Wide-Angle Free-Air Chamber
WG	Working Group
WHO	World Health Organization
WISE	Women in Science and Engineering
WKB	Wentzel-Kramers-Brillouin
WWV	Call letters for NIST short-wave radio station in Colorado
WWVB	Call letters for NIST lf radio station in Colorado
WWVH	Call letters for NIST short-wave radio station in Hawaii
XROI	X-Ray Optical Interferometer
XSW	X-ray Standing Wave
YAG	Yttrium-Aluminum-Garnet