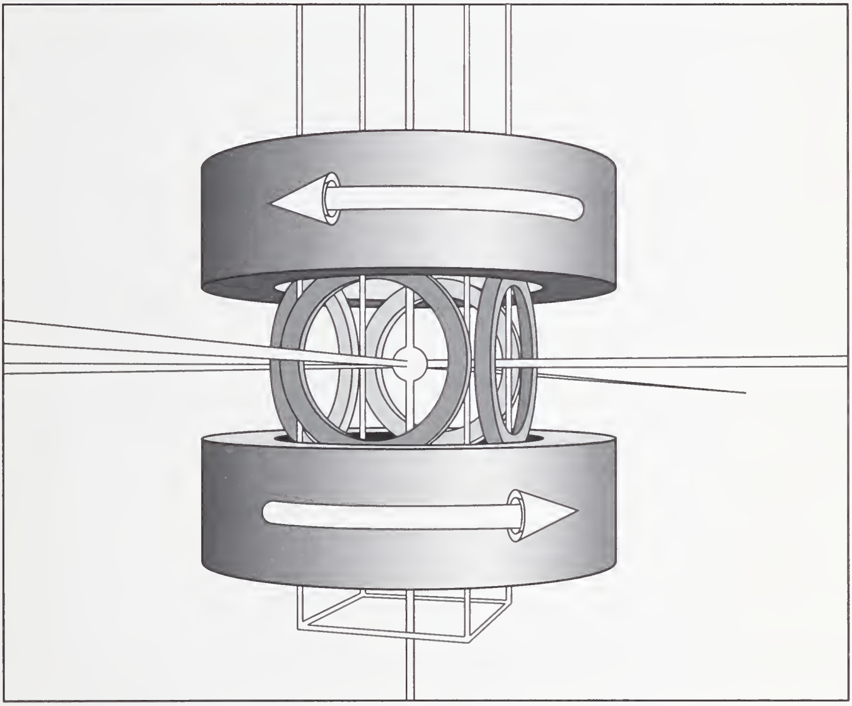
NISTIR 5922

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

Submitted to the Board on Assessment of
NIST Programs,
National Research Council
February 4-5, 1997

PHYSICS LABORATORY

Technical Activities 1995-1996



NIST

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January 1997

U.S. DEPARTMENT OF COMMERCE
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Technology Administration
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National Institute of Standards and Technology
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DESCRIPTION OF COVER ILLUSTRATION

Magneto-optical trap. Schematic of the apparatus used to cool atoms to almost absolute zero, resulting in the world's first demonstration of Bose-Einstein Condensation. Six laser beams intersect in a glass cell placed between magnetic coils, creating a magneto-optical trap (MOT). The glass cell hangs from a chamber (not shown) containing a vacuum pump and rubidium source. Also not shown are coils for injecting the rf magnetic field for evaporation and the additional laser beams for imaging and optically pumping the trapped atom sample.

TECHNICAL ACTIVITIES

ABSTRACT

This report summarizes research projects, measurement method developments, calibration and testing services, and data evaluation activities that were carried out during calendar years 1995 and 1996 in the NIST Physics Laboratory. These activities fall in the areas of electron and optical physics, atomic physics, optical technology, ionizing radiation measurements, time and frequency measurements, quantum physics, fundamental constants, and electronic dissemination of scientific information and data.

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

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TECHNICAL ACTIVITIES

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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 1995 to December 1996. The Laboratory is one of eight major technical units of NIST.

The mission of the Physics Laboratory is to support U.S. industry by providing the best possible foundation for metrology of optical and ionizing radiation, time and frequency, and fundamental quantum processes. The Physics Laboratory carries out this mission by conducting long-term research in measurement science; developing new physical standards, measurement methods, and critically compiled scientific and engineering reference data; promulgating these standards, methods, and data by providing calibration measurement services, standard reference materials, and electronic information services, and by publishing research results, holding conferences, and conducting workshops; participating in quality-assurance programs; and collaborating with industry, universities, and other agencies of government. Physics Laboratory maintains the U.S. national standards for the Système International (SI) base units of the second, the candela, and the kelvin (above 1200 K) as well as such SI derived units as the hertz, the becquerel, the optical watt, and the lumen.

Science and technology, once considered separate and sequential, are now becoming increasingly merged. Consistent with this trend, the Physics 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 industry, academia, and government, and include the other Laboratories of NIST. Its scope spans technologies based upon electronic, optical, and radiation-induced effects.

To tighten the relation between the performers of directed research and the industrial developers of advanced technologies, scientists in the Physics Laboratory work with industry and the other Laboratories of NIST to develop new measurement technologies that can be applied to areas such as communications, microelectronics, magnetics, photonics, lighting, industrial radiation processing, the environment, health care, transportation, defense, energy, and space. Cooperative research and development agreements, industrial research associates, committee participation, and consultations are all powerful mechanisms for transferring measurement capability to the private sector.

The Physics Laboratory has identified four strategic areas where it believes its experience and distinctive skills can contribute best to industrial and critical national needs, by providing measurement methods, instrumentation, standards, and data for:

- ***electronic and magnetic devices*** - to develop innovative measurement methods and techniques of use to the electronics industry for device characterization and electronic information and communication;
- ***optical technology*** - to provide the national basis for optical radiation measurement and to develop optical measurement systems for industrial and environmental needs;
- ***radiation applications and control*** - to support the innovative, effective, and safe use of radiation by providing standards and measurement quality assurance services, by developing and evaluating new radiation measurement methods, and by providing critical data;
- ***fundamental physical quantities*** - to improve definitions and realizations of base and derived SI units and to pursue opportunities for new determinations of fundamental physical constants.

The Laboratory's focus on atomic, molecular, optical, solid state, and ionizing radiation physics reflects the continuing importance of these disciplines in developing new measurement technology to address the needs of U.S. industry.

The Laboratory establishes spectroscopic methods and standards for microwave, infrared, visible, ultraviolet, x-ray, gamma-ray, and particle radiation; investigates the structure and dynamics of atoms and molecules, singly and in aggregate; and applies these results for practical purposes.

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 technical programs in NIST, the nation, and other institutions throughout the world. It conducts a major cooperative research program with the University of Colorado through JILA.

Whatever the criteria of success, the Laboratory is among the world's leaders in basic and applied metrology. Its most productive scientists appreciate an environment where they can con tribute to important practical programs as well as to strategic, fundamental research. The Laboratory's great strengths include not only its multiple contributions to basic physics, chemistry, and materials science and its seminal role in fundamental measurement technology, but also the application of this measurement technology to specific industrial requirements.

The Physics Laboratory consists of six Divi sions.

■ **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 theoretical and experimental research into the spectroscopic and radiative properties of atoms, molecules, and ions to provide measurement and data support for national needs in such areas as fusion plasma diagnostics, processing of materials by plasmas, spectrochemistry, illumination technology, and laser development; carries out high accuracy determinations of optical, ultraviolet, x-ray, and gamma-ray transition energies; develops atomic radiation sources as radiometric and 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 analyzing spectroscopic data, for measuring plasma properties such as temperature and densities, and for determining fundamental physical constants; carries out theoretical and experimental research on quantum processes in atomic, molecular, and nanoscale systems, such as optical control of matter and semiconductor nanodevices and technologies; and collects, compiles, and critically evaluates spectroscopic data and creates databases to meet major national demands.

■ **Optical Technology Division.** Provides national measurement standards and support services to advance the use and application of optical technologies spanning the ultraviolet through microwave spectral regions for diverse industries and governmental and scientific use; develops radiometric, photometric, spectroscopic, and spectrophotometric measurement methods, standards, and data; and promotes accuracy and uniformity in optical radiation based measurements through standards dissemination and measurement quality assurance services; to improve services and increase the accuracy, range, and utility of optical technologies, conducts basic, long-term theoretical and experimental research in optical and photochemical properties of materials, in radiometric and spectroscopic techniques and instrumentation, and in application of optical technologies; through these activities, meets the needs of industries such as the lighting, photographic, automotive, and xerographic industries; and provides measurement support to national needs in solar and environmental monitoring, health and safety, and defense.

■ **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-characterized 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 stan dards for time and frequency and the time scales based on these standards; carries out research in areas of importance to the further fundamental improvement of frequency standards and their applications, focusing on microwave and laser devices, atomic and molecular resonances, and the measurement of fundamental physical phe nomena and constants; adapts time and frequency standard devices and concepts to special scientific and technological demands; develops time and frequency measurement methods in the radio-frequency, 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) Provides fundamental, highly accurate measurements and theoretical analyses using quantum physics, quantum optics, chemical physics, gravitational physics, and geophysical measurements; develops the laser as a refined measurement tool; measures and tests the fundamental postulates and natural constants of physics; applies atomic, molecular, and chemical physics to understand predict, and control properties of excited and ionized gases and the pathways of chemical and material processes relevant to technology; improves the theory and instrumentation required to measure quantities such as Earth's gravity, local gravity, and terrestrial distances; and maintains, through its association with JILA, the University of Colorado, and JILA's Visiting Fellows Program, active contact with the education community.

In addition, two groups operate under the direct supervision of the Laboratory Office.

■ **Fundamental Constants Data Center.** Provides a centralized international source of information on the fundamental physical constants, closely related precision measurements, and the international system of units; and periodically develops and widely distributes, in collaboration with outside international organizations, sets of recommended values of the fundamental constants.

■ **Office of Electronic Commerce in Scientific and Engineering Data.** Coordinates and facilitates the dissemination of scientific and engineering data, generated by the Physics Laboratory, by means of available electronic networks; promotes the organization of the delivery of scientific, engineering, and technical data from its producers and publishers to U.S. industry by electronic means in the standard formats and computer readable forms required by U.S. industry for its timely and effective use; and coordinates the National Information Infrastructure initiatives of the Physics Laboratory.

ORGANIZATION OF REPORT

This technical activities report is organized in seven sections, one for the Physics Laboratory Office, which includes the Fundamental Constants Data Center and the Office of Electronic Commerce in Scientific and Engineering Data, and one for each of the six 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 sections are Appendices that 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, they have nothing to report in this category.

To obtain more information about particular work, the reader should address the individual scientist or the Division office, % Physics Laboratory, Physics Building Room B160, National Institute of Standards and Technology, Gaithersburg, Maryland 20899-0001 ▫

FUNDAMENTAL CONSTANTS DATA CENTER

B. N. Taylor

MISSION

- provide an international information center on the fundamental constants and closely related precision measurements;
- 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;
- administer the NIST Precision Measurement Grant (PMG) Program;
- provide the editorship of the *Journal of Research of the National Institute of Standards and Technology*;
- serve as the NIST-authorized organization for the interpretation of the International System of Units (SI) in the United States.

CURRENT DIRECTIONS

■ **Measurement Uncertainty.** Contribute to an international effort under the auspices of the International Organization for Standardization (ISO) to generate and widely distribute a guide on expressing measurement uncertainty, and to have it adopted worldwide.

■ **Information Center.** Maintain an extensive collection of reprints and other material relating to fundamental constants and precision measurements 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 by the end of 1997 and will provide a new set of recommended values of the constants for international use. This effort includes maintaining the Data Center's bibliographic data base on the fundamental constants on the Physics Laboratory's World Wide Web (WWW) home page.

■ **Constants Adjustment.** Carry out the work necessary to complete the 1997 CODATA constants adjustment.

■ **Precision Measurement Grants.** Implement policies to ensure that this grant program continues to attract proposals of the highest quality and provides maximum benefit to NIST.

■ **NIST Journal of Research.** Implement policies to 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 report the results of their research in measurement.

■ **SI Units.** Generate publications related to the International System of Units (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 for the Use of the SI—1995 Edition of NIST SP 811.** We prepared, published, and widely distributed a new edition of NIST Special Publication (SP) 811, *Guide for the Use of the International System of Units (SI)*.

The 1995 edition of SP 811 corrects a number of misprints in the 1991 edition (prepared by A.O. McCoubrey), incorporates a significant amount of additional material intended to answer frequently asked questions concerning the SI and SI usage, and updates the bibliography. The added material includes a check list for reviewing the consistency of written documents with the SI. Some changes in format have also been made in an attempt to improve the ease of use of SP 811.

To date, nearly 15,000 copies have been distributed throughout the world. These include copies to the NIST technical staff, to the members of the National Conference of Standards Laboratories, to the Members and Corresponding Members of the International Organization of Legal Metrology, to the Committee Delegates, Rapporteurs, and Contact Persons of EUROMET (a European collaboration in measurement standards) and of NORAMET (a North American regional collaboration in national measurement standards and services), to the members of the Council on Optical Radiation Measurements and of the Council on Ionizing Radiation Measurements and Standards, and to numerous readers of many different trade magazines, newsletters, technical journals, etc. SP811 is also available on the WWW home page of the Physics Laboratory.

■ **Precision Measurement Grants.** We awarded, on behalf of NIST, new Precision Measurement Grants to Siu Au Lee of Colorado State University and Jonathan Sapirstein of the University of Notre Dame. The grants are in the amount of $50,000 per year, renewable for two additional years. NIST sponsors these grants to promote fundamental research in measurement science in U.S. colleges and universities and to foster contacts between NIST scientists and researchers in the academic community actively engaged in such work.

The aim of Sui Au Lee's project is to directly measure, for the first time, the birefringence of light propagating in vacuum in a strong magnetic field, and to conduct an improved laboratory search for axions. This work is based on the prediction that when a beam of light travels in vacuum in a strong applied magnetic field, the quantum electrodynamic (QED) vacuum polarization induces a small change in the index of refraction of the vacuum. Because the index change depends on the polarization of the beam relative to the direction of the field, the vacuum acquires a birefringence. Although this QED effect has never been observed, the recent development of long, high-field superconducting magnets and the progress made in developing low-loss mirrors for laser gyroscopes and laser gravitational detectors has now made its observation feasible. This is a unique opportunity to carry out a new test of QED, the most accurate theory of modern physics.

The aim of Sapirstein's project is to improve the theory of the energy levels of atomic helium. Accurate measurements of various energy levels of helium and helium-like ions have been and are continuing to be carried out. Of particular interest are recent measurements of the fine structure of helium with a relative standard uncertainty of 1×10^{-7}, and their expected significant improvement. These can be used to determine one of nature's most important fundamental constants, the fine-structure constant α, provided the theory has a comparable uncertainty. One of Sapirstein's goals is to extend the existing Bethe-Salpeter equation calculations, which include all corrections of order α^2 relative to the fine structure, to all corrections of order α^3. When the α^3 corrections are known, a value of α will be available from helium that can be compared with values obtained from the quantum Hall effect (QHE); and from the quantum electrodynamic (QED) theory of the magnetic moment anomaly of the electron a_e and its experimental determination. This will provide a new, critical check on the theory of the QHE and of the internal consistency of QED.

FUTURE OPPORTUNITIES

During the next one to two years, we will focus on (1) continuing to provide guidance to the NIST staff and others on expressing measurement uncertainty based on the ISO *Guide to the Expression of Uncertainty in Measurement* and on NIST TN 1297; (2) finalizing an ANSI/ASTM-IEEE joint U.S. standard on metric practice, collaborating with other members of the Consultative Committee on Units of the CIPM on revising the BIPM SI Brochure, and revising NIST Special Publications 330 and 811 on the SI; (3) maintaining, in collaboration with Peter J. Mohr of the Physics Laboratory's ECSED program and Atomic Physics Division, the Data Center's fundamental constants bibliographic database on the Physics Laboratory's WWW home page; and most importantly; (4) providing the chairmanship of the CODATA Task Group on Fundamental Constants, carrying out the work necessary for completing the 1997 CODATA least-squares adjustment of the constants, and widely disseminating the resulting recommended values of the constants. □

OFFICE OF ELECTRONIC COMMERCE IN SCIENTIFIC AND ENGINEERING DATA

MISSION

- coordinate and facilitate the dissemination of Physics Laboratory-generated scientific and engineering data by means of computer networks;
- develop methods and serve as a model for the effective dissemination of scientific and engineering information by means of computer networks;
- promote compatibility and integration in the electronic delivery of scientific, engineering, and technical information from its producers and publishers to U.S. industry through the use of common standards and formats;
- coordinate the National Information Infrastructure initiatives of the Physics Laboratory.

CURRENT DIRECTIONS

▪ **Dissemination of Physics Laboratory Information over the Computer Networks.** The Office of Electronic Commerce in Scientific and Engineering Data (ECSED) is responsible for the Physics Laboratory World Wide Web (WWW) pages. It produces Physics Laboratory (PL) material for publication over the WWW, encourages and supports the production of material by others, and assures the high quality of information disseminated by PL over electronic networks. It develops methods to display information generated within PL in an effective manner over the WWW. This Office also is engaged with the PL Divisions in developing physical reference databases for dissemination over the WWW. It designs effective interfaces between the information and the user to facilitate use of the data.

▪ **Electronic Commerce in Scientific and Engineering Data.** This Office works to promote compatibility and integration in the dissemination of non-product-specific information required by U.S. industry. It seeks to make scientific, engineering, technical, codes/standards, and related regulatory information available to U.S. industry in a usable, accessible, unified manner.

Work on this effort began with an industry/government team organized in conjunction with the National Initiative for Product Data Exchange (NIPDE). The team identified and defined 19 specific functions that are needed to make such an information capability a reality. We are creating a WWW page to identify the required functions and provide information about progress in each of them. In addition, we plan to make our WWW databases available to developers as testbeds to demonstrate their methods of achieving these functions. This WWW page will serve both to inform the data producing and using communities about progress towards an effective dissemination system and to encourage the computer technology community to build the capabilities necessary for technical data into its systems. In addition, the databases disseminated by PL on its WWW page will serve as models of effective dissemination of scientific and engineering data.

▪ **Represent Physics Laboratory in Information-Related Activities within NIST and Nationally with Physics-Related Organizations.** These activities included active participation with the NIPDE in the areas of information dissemination. Work continues with various groups within NIST concerned with electronic information dissemination and with a professional society.

HIGHLIGHTS

▪ **The Physics Laboratory Information on the World Wide Web.** The Office of ECSED provides Physics Laboratory information and data over the WWW to U.S. industry and the general public. This information has been accessible to the public since June 20, 1994 at the URL http://physics.nist.gov/. By the end of fiscal year 1996, we were supplying 50,000 PL documents each month to users outside of NIST (fully half from our databases). The rate of use continues to increase rapidly.

A wide range of information is provided by PL on the WWW. It includes staff and organization information, PL technical activities, publication lists, research facilities, physical reference data, and bibliographic information about physical reference data. New information is added regularly. We develop programs to provide this information and innovations to overcome the limitations of current browsers.

■ **Atomic spectroscopic database developed for PL WWW page and for NASA's Astrophysics Data System.** The Atomic Spectroscopic Database was developed in a collaboration between the Astrophysics Data System, the Atomic Physics Division, the NIST Standard Reference Data Program, and the Office of ECSED. It includes most of the existing critically evaluated NIST data on atomic energy levels, transition probabilities, and wavelengths that are reasonably up-to-date. This interactive database has energy level data for over 500 spectra, transition probabilities for Sc through Ni, and wavelength data for spectra of several elements. It involves obtaining requested data from a repository computer and delivering it to the user through a WWW page on another computer system.

■ **Database with sophisticated user interface developed for the WWW.** The Office of ECSED has developed a WWW version of the database entitled Wavenumber Calibration Tables From Heterodyne Frequency Measurements, by Arthur G. Maki and Joseph S. Wells. This is an atlas of molecular spectra and associated tables of wavenumbers for the calibration of infrared spectrometers. Molecule and spectral range can be selected by clicking within WWW browsers. When the graphical presentation is generated for the user, he/she may then modify the display by changing the range displayed and clicking on a new center point. Other modifications of the display can also be made at the choice of the user. This and several other databases developed by the Office of ECSED for the WWW are available online from the PL WWW page.

■ **Astrophysical molecular database developed for the WWW.** A web version of the database of critically evaluated molecular transition frequencies detected in interstellar and circumstellar clouds, recommended by NIST for reference in future astronomical observations in the microwave and millimeter wavelength regions, was developed in collaboration with the Optical Technology Division. This database can be searched online by frequency and/or molecule, telescope, or reference. Detailed information and references are provided for the transitions.

■ **Wide range of databases developed for WWW dissemination.** This Office has developed and makes available over the WWW a wide range of physical reference databases. In addition to the three mentioned above, we provide databases of the Fundamental Physical Constants, Spectrum of a Platinum Lamp, Bibliographic Database on Atomic Transition Probabilities, X-Ray Attenuation and Absorption for Materials of Dosimetric Interest, and Bibliography of Photon Attenuation Measurements. Each of these databases was developed for the WWW in close collaboration with the compilers of the information and has an interface appropriate for its intended use. Databases are improved and information is added to them on an ongoing basis.

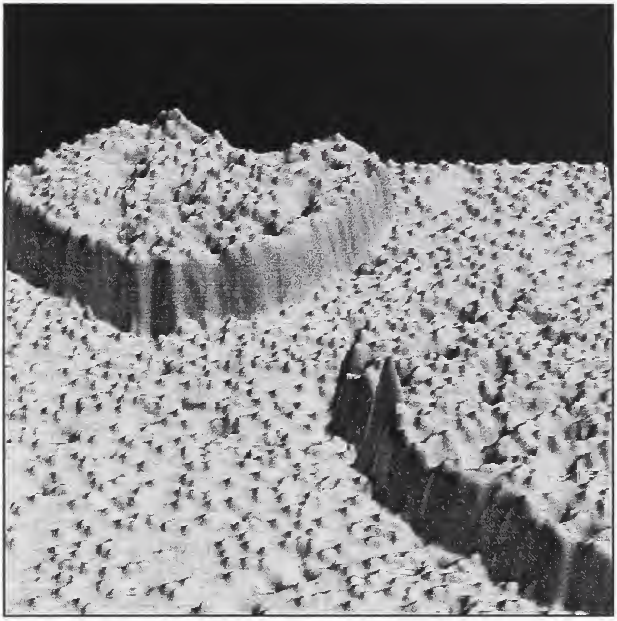
■ **Electronic Commerce in Scientific and Engineering Data.** A draft of the report of the industry/government team was circulated to all participants. A revised report was completed and was posted on the NIPDE WWW page for 18 months. We have prepared a draft of the ECSED Testbed — a WWW page encompassing updated information from this report as well as links to activities supporting ECSED functions and future opportunities for demonstrating ECSED functions. After appropriate reviews are completed, it will be made available on the WWW. This WWW page will aid technical database developers in keeping current on developments in the electronic dissemination of information.

FUTURE OPPORTUNITIES

During the next year the Office of Electronic Commerce in Scientific and Engineering Data will continue adding to the information disseminated on the PL WWW pages. New information is expected to include a database of form factor, attenuation, and scattering tables, a report that describes methods and computer programs for calculating absorbed-dose distributions in a water target irradiated by proton beams, a bibliographic database for atomic energy levels, a bibliographic database for fundamental constants, and a new atomic spectroscopic database. The Office will advance its mission to promote compatibility and integration in electronic commerce of scientific and engineering data by establishing its ECSED testbed on the WWW. ▫

TECHNICAL ACTIVITIES

ELECTRON AND OPTICAL PHYSICS DIVISION



Overleaf

Scanning tunneling microscopy image. Scanning tunneling microscopy image of single atomic-step islands resulting from the deposition of Cr on Fe(001) at 300 C. The deposited Cr forms an alloy with Fe substrate resulting in substrate and island levels composed of mostly Fe with a low concentration of isolated Cr impurities. The individual Cr impurities are the slightly raised features decorating both levels.

ELECTRON AND OPTICAL PHYSICS DIVISION

MISSION

The Electron and Optical Physics Division's mission is to develop measurement capabilities needed by emerging electronic and optical technologies, particularly those required for submicron fabrication and analysis.

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 extreme ultraviolet (EUV) regions of the electromagnetic spectrum, which together span the photon energy range of 5 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, other NIST organizational units, and external research groups.
- maintains specialized 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 studying surface structure and dynamical phenomena, and for developing the basic measurement techniques necessary for atomic-level device fabrication.
- maintains an EUV optics characterization facility to perform measurements of EUV optical components and systems, and to support applications of such optics in microlithography, microscopy, and telescopy.
- performs theoretical and experimental research in atomic and condensed matter physics in support of its basic mission objectives.

ORGANIZATION

The Division consists of three groups, which together employ about 33 full-time equivalent members of staff, and during the past year had the equivalent of 12 Guest Researchers working full-time during visits of three or more months.

The Photon Physics Group (841.01) is primarily engaged in research in EUV optics, the development of EUV and x-ray microscopy, and the generation of coherent far ultraviolet radiation. It also operates an EUV optics characterization beamline at SURF II that provides custom calibrations for the soft x-ray optics community, the only such dedicated facility in the United States. Presently the Group is in the process of establishing an infrared microscope facility at SURF for use by the polymer, semiconductor, forensic, and medical communities.

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 to 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 and laser manipulation of atoms. 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 studying 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 now applied its capabilities in these areas to attain a position of world leadership in the laser control of atomic adsorption on surfaces.

The Division was saddened by the loss of Dr. Richard Watts of the Photon Physics Group, who died on November 16, 1996. Rich was a productive member of the technical staff, and his contributions to the EUV optics program and to the development of an x-ray microscope were major components of the Photon Physics Group's output during his tenure.

CURRENT DIRECTIONS

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

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 completion of a major renovation which has resulted in a substantial increase of user space and a general enhancement of amenities.

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 grating efficiencies and film dosimetry. In 1995-1996 measurements were made on over 180 samples, provided primarily by industrial laboratories, other government agencies and universities. These services are presently undertaken primarily as research collaborations, not on a reimbursable basis. As described below, a new reflectometer is under construction to accommodate the large, heavy optics that will be forthcoming in the field of projection lithography. Two other measurement service 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. 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.

A new IR microscope facility is presently under construction. As recently demonstrated at the NSLS at Brookhaven, synchrotron sources of IR radiation can be vastly superior to conventional sources. Both the NSLS and SURF synchrotron are over two orders of magnitude brighter in the IR region from 2 to 30 μm than the conventional globar sources. Thus the recently commissioned IR microscope at the NSLS has been overwhelmed by demand from the polymers, forensic, geochemical, semiconductor, and medical communities because of the marked increased sensitivity it can provide. The NIST facility is expected to be operational early in 1997.

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 principal research activities of the Photon Physics Group, the other main research-oriented group in the Division, are in EUV physics, and are carried out in close association with the EUV Optics Characterization Facility 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.

TECHNICAL HIGHLIGHTS

■ **Calibrations and Instrumentation Development at the NIST/ARPA National EUV Reflectometry Facility.** The NIST/ARPA National EUV Reflectometry Facility at SURF II, the only such facility in the U.S. open to all members of the EUV community, entered its fifth year of operation. Over 180 calibrations were performed in 1995-1996 on a variety of mirrors, gratings, photocathodes, and photographic emulsions for collaborators in industry, national laboratories, and universities. Fabrication of a new reflectometer is well underway and should be completed this summer. The new reflectometer, which we expect to install in 1997, will be able to accommodate optics up to 35 cm in diameter and 40 kg in mass. This capability, which will be unique, is necessary for the characterization of large optical components required for EUV projection systems. (T.B. Lucatorto, C.S. Tarrio, and R.N. Watts)

■ **First Demonstration of Figuring by Multilayer Deposition.** As part of our continuing effort to support the semiconductor industry's interest in EUV lithography as a possible technology for future generation devices, we have begun studies to determine the limits of using multilayer deposition as a post-polishing technique for the fabrication of precision EUV optics. Thus far, traditional polishing has not been able to simultaneously produce optics with the figure and finish requirements for such advanced applications. Our previous experience with making EUV multilayer mirrors has given us confidence that the multilayer technique has the potential to make large changes in surfaces (such as aspheric corrections to high-quality spheres) with virtually no addition of roughness. During this period we have demonstrated the method for rotationally symmetric errors. We are currently investigating the limits of two-dimensional corrections. (C. Tarrio, E. Spiller, T.B. Lucatorto)

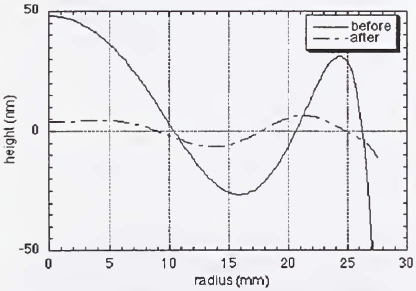


Figure 1. Figuring by deposition: a radially symmetric error was polished into a glass test piece. The solid line is the error measured using phase-measuring interferometry. A mask was constructed from this, and a Co-C multilayer was deposited through the stationary mask onto the rotating sample. The corrected figure (dashed line) shows almost a factor of ten improvement.

■ **Extreme Ultraviolet Microscope Project.** In collaboration with H. Milchberg of the University of Maryland, we have recently begun an effort to construct an extreme ultraviolet Schwarzschild microscope with the eventual goal of imaging live biological specimens. The ultimate success of the NSF-sponsored program rests on two unique capabilities: the correction and asphierization of the optical figures (see above) to unprecedented accuracy, and the generation of high-intensity, ultra-short EUV radiation using high-harmonic generation. The optical design for a first-generation prototype using spherical optics at a wavelength of 13 nm has been completed and construction is underway. The final microscope is anticipated to use at least one aspherical surface and work in the water window (2.5 nm to 4.4 nm). (C. Tarrio, E. Spiller, and T.B. Lucatorto)

■ **SURF III Upgrade.** The present SURF II facility, built in 1974, is soon to undergo a major overhaul designed to improve its performance for radiometry and other scientific applications. In 1994, a contract was let with the University of Wisconsin (UW), which built SURF II, to study the available options leading to improved performance. Following that report, delivered in July 1995, a second contract was let with UW to provide a detailed design for the selected approach. That report was delivered in May 1996, and a construction contract with UW was let on September 27, 1996.

The most important aspect of the SURF III concept is improved radiometric accuracy. The magnitude and angular distribution of the flux radiated by SURF III will be much more accurately characterized through a better knowledge of the electron energy and trajectory in the storage ring and improved methods of determining the electron current. The improved accuracy of the electron orbit will be achieved by more stringent mechanical tolerances on the magnet, better steel, and optimized magnet design. Thus the SURF II magnet, iron and coils, will be replaced, and the control system will be overhauled. As a result of the improved iron in the magnet, a significant gain in field strength will also be realized, allowing the maximum achievable energy of the electrons in the storage ring to be increased from the 300 MeV for SURF II to close to 400 MeV for SURF III. This will allow radiometry and scientific applications to be carried out down through the water window to a wavelength of about 2.5 nm ($\sim$500 eV). Changes to the storage ring itself are planned to increase the number of beamlines available by two, and to increase the solid angle of collection of the infrared beamline to 90 μrad. This will be an important enhancement for this new application of SURF III, a source which will be competitive with the best in the world in the infrared spectral region.

The assembly of the SURF III magnet system is scheduled to begin in October 1997, with commissioning complete on April 1, 1998. If this schedule holds, we will cease normal operations at SURF II on about July 1, 1997 to begin dismantling the SURF II magnet system and prepare the site for the new one. (A. Hamilton, L. Hughey, and R. Madden)

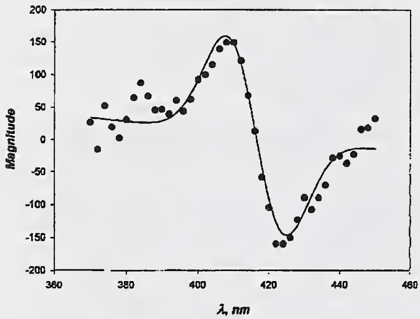


Figure 2. Electroreflectance spectrum of cytochrome-c immobilized on an evaporated gold electrode modified with N-acetyl cysteine, as obtained on the UV beamline at SURF II. Signal is relative change in reflectance in units of 10^{-6}, so that the maximum change exhibited here is about 1.5×10^{-4}. Solid line shows expected spectrum.

■ **Protein Electroreflectance Studies at SURF II.** Adolfas Gaigalas of the Biotechnology Division has set up an apparatus on beamline 5 at SURF II for the measurement of electroreflectance from metal surfaces with adsorbed proteins. This technique requires the measurement of the change in reflectance induced by a sinusoidally varying applied potential. The bare metal surface has a characteristic reflectance signature in the 250 to 400 nm spectral region due to electron plasma oscillations. However, adsorbed species can alter the signal dramatically. This is especially true if the adsorbed molecule is a protein with a metal site which can be reduced and oxidized by electrons from the electrode. The photon absorption tends to be very different in the two redox states leading to a large reflection modulation amplitude, which can be used to determine electron transfer rates between certain metaloproteins and electrodes. Adolfas is finding that synchrotron radiation from SURF II is highly stable, continuously tunable, and gives him greatly improved signal-to-noise over other available laboratory sources. He observes intrinsic intensity noise at a level of 10^{-5} in the 10 to 100 Hz region, of paramount importance for observing electroreflectance modulations of typical magnitude 1 part in 10^4. These are results obtained in his first experiment, performed in September/October 1996, on cytochrome-c immobilized on an evaporated gold electrode. (R. Madden)

■ **Activity at the SURF Spectrometer Calibration Facility.** During 1995 and 1996 there were 26 instruments calibrated by 7 user Groups at the Spectrometer Calibration Facility at SURF II. Users of the facility included Lawrence Livermore National Laboratory, Naval Research Laboratory, National Institute of Standards and Technology, University of Southern California Space Sciences Center, NASA Goddard Space Flight Center, and the National Center for Atmospheric Research High Altitude Observatory (NCAR/HAO).

Lawrence Livermore researchers calibrated their SPRED UV spectrometer with multiple gratings in the wavelength range 10 to 200 nm. The instrument is used to characterize impurities and impurity transport in fusion experiments at the DIII-D tokamak at General Atomics in San Diego.

NCAR/HAO scientists calibrated a number of detectors for two NASA experiments. The XUV Imaging of the Solar Corona experiment will provide helium and hydrogen abundances in the solar corona. The TIMED/Rocket Solar EUV experiment will explore the energy balance of the upper atmosphere above 60 km. (M. Furst and R. Graves)

■ **Activity in Transfer Standard Detector Calibrations.** New detection devices suitable for standards use in the far ultraviolet are being explored. Filter radiometer photodiodes useful in solar physics and in plasma diagnostics, for example, have been extensively characterized in collaboration with industry and academia. A new form of semiconductor detector, a platinum silicide Schottky barrier silicon photodiode, has been studied and looks very promising. Silicon photodiodes with hardened oxide have been developed in collaboration with industry, and are now routinely issued as NIST calibrated transfer standard detectors for the far ultraviolet, from 5 to 250 nm.

Special calibrations of filter radiometer instruments designed to monitor the He II 30.4 nm emission line were made at the SURF II facility in collaboration with industry, academia, and NOAA. A primary flight instrument is successfully monitoring the solar irradiance aboard the SOHO international spacecraft, launched in 1995. Several similar underflight instruments have also been characterized.

Sixty-three calibrations of transfer standard detectors were performed during 1995-1996 for applications in astronomy, aeronomy, solar physics, and plasma diagnostics. A number of special radiation filters were also characterized in research collaborations. (L.R. Canfield and R. Vest)

■ **Chemical Identification of Alloys on the Atomic Scale.** As part of our research on magnetic multilayers, we have identified alloying that occurs in the Cr/Fe(001) system with atomic scale resolution using scanning tunneling microscopy. Our work on magnetic multilayers is motivated by the fact that these systems exhibit phenomena of exchange coupling and giant magnetoresistance that have technological application in areas such as magnetic recording and non-volatile memory storage. Research and development in this area has proven challenging because magnetic properties are strongly influenced by structural details which can be difficult to characterize and control. In this regard, much progress has been made by studying epitaxial Fe/Cr/Fe structures where growth can be controlled to a large extent; however, some of the magnetic properties of this system have remained anomalous. The alloying which we have identified at the Cr/Fe interface may in part be the cause of these anomalies.

Scanning tunneling microscopy measurements after submonolayer deposition of Cr on Fe(001) at 300 °C show the formation of single atomic step islands on the surface (Fig. 3). If alloying did not occur, the islands would be pure Cr on top of the Fe(001) substrate. A high resolution image of the surface showing the substrate (central region in Fig. 3b) and island levels (regions surrounded by a thick black line in Fig. 3b) indicates that both levels are not chemically uniform but are an Fe/Cr alloy. The white dots are the individual alloyed Cr atoms surrounded by Fe. The imaging contrast is due to the electronic difference between the Fe and the Cr and leads to the perceived small height contrast between the elements in the STM image (Fig. 3c). (A. Davies, J.A. Stroscio, D.T. Pierce, and R. Celotta)

■ **Reflection in Magnetic Multilayers.** In magnetic multilayers, electrons in one material can reflect from interfaces between the two materials. This reflection contributes to two important effects, oscillatory exchange coupling and giant magnetoresistance. Exchange coupling between the magnetizations of magnetic layers is the coupling that is mediated by the electrons in a non-magnetic spacer layer which separates them. For some systems it oscillates in sign as a function of the spacer layer thickness and for particular thicknesses gives antiparallel alignment of the magnetizations in neighboring magnetic layers when there is no applied field. The giant magnetoresistance is the change in resistance when the relative orientation of the magnetizations is switched by applying a magnetic field. Devices based on the giant magnetoresistance effect have been proposed as magnetic field sensors and read heads in magnetic disk storage.

To better understand such systems, we have calculated reflection probabilities for a series of noble metal spacer layers and lattice-matched ferromagnetic layers from first principles. These calculations show strong spin dependence for all systems considered. The strong spin-dependence results because the bands of the spacer layer

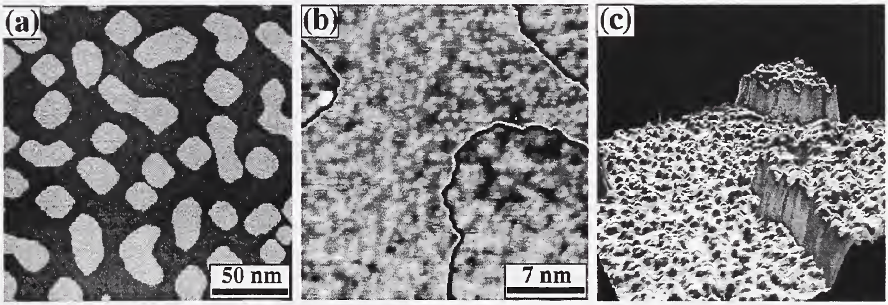


Figure 3. STM images of Cr growth on Fe(001).

match well with the majority bands of the ferromagnetic layers, but poorly with the minority bands. The calculated reflection probabilities lead to predictions of the coupling strength that will be measured in these systems as the quality of growth continues to improve. The predictions are much larger than measured values, but the measured strengths continue to increase as better experiments are done. These results also suggest that the contribution to the giant magnetoresistance from a process called channeling can be quite substantial, particularly in the Fe/Au(100) and Fe/Ag(100) systems. (M.D. Stiles)

■ **Magnetic Hysteresis in Ultrathin Films.** The performance of devices based on ultrathin magnetic films depends on the films' coercivity, i.e., the field required to reverse the magnetization. In most magnetic systems, defects reduce the coercivity below the value predicted by simple models based on uniform rotation of the magnetization. Understanding the effect of defects on coercivity will lead to the ability to predict and control the magnetic behavior of ultrathin films.

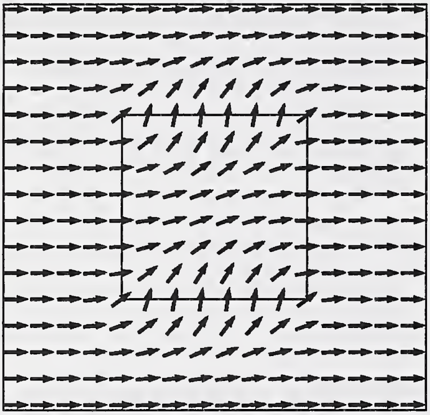


Figure 4. A typical configuration of spins in an ultrathin film in remanence. The square in the center is a magnetic island on the film. Due to the anisotropy at the step edge, the magnetization is starting to reverse.

In collaboration with scientists at the Georgia Institute of Technology, we have theoretically modelled magnetic hysteresis in ultrathin films. We have shown that for ultrathin films, defects as small as single atomic steps can determine the coercivity. Even the best ultrathin films have step edges associated either with the perimeter of monolayer-height islands that nucleate during growth or with the steps of an unavoidably miscut crystal substrate. Because the steps have reduced crystallographic symmetry, the magnetic anisotropy at steps can be large compared to the intrinsic anisotropy of the flat surface. This large, local anisotropy leads to non-uniform magnetization reversal. In particular, rotated domains, which are nucleated at the step edges, start the reversal at fields much lower than the field required for uniform reversal. Situations where steps control the magnetization reversal have the feature that the properties of the steps can be readily measured. In these situations, it will be possible to make a stringent comparison of theory and experiment. (M.D. Stiles)

■ **SEMPA Observation of Large Magnetic Domains in Magnetoresistive Granular Metals.** Using the new high resolution SEMPA facility, Electron Physics Group researchers showed that large (100 nm) magnetic domains exist in cobalt-silver granular metals (Fig. 5). Few researchers anticipated large magnetic domains in granular Co-Ag: the microstructure of these materials was thought to limit the magnetic domains to sizes comparable with the particle size (less than 10 nm). The presence of large domains is particularly noteworthy because these materials exhibit the giant magnetoresistance effect (GMR), which has many potential applications. The presence of large domains implies that a significant fraction of the cobalt in these materials does not contribute to the giant magnetoresistance.

Figure 5. SEMPA image of magnetic domain structure in Co0.35Ag0.65. Typical dimension of magnetic domain is 300 to 600 nm.

In collaboration with researchers at The Johns Hopkins University, members of the Electron Physics Group have investigated the composition and fabrication parameters that lead to the presence of large domains, and have suggested two alternate models for their origin. The domains may represent correlations among large numbers of isolated cobalt particles, or they may be due to residual cobalt in the silver matrix. A report of this work was published in Applied Physics Letters. (M.H. Kelley and A. Gavrin)

▪ **Laser-Focused Deposition of Chromium "Nanodots".** Building on our earlier work on making chromium "nanolines" by focusing atoms in a laser standing wave, we have succeeded in making an array of chromium "nanodots" on a silicon surface. While the earlier experiments used a single standing wave grazing across the surface of a silicon wafer to make a one-dimensional pattern, the new work employs two laser standing-waves at 90° to each other. At the intersection of the two beams a two-dimensional optical standing wave is created, whose nodes act as atom-optical lenses for chromium atoms being evaporated onto the surface. The atoms are concentrated at the nodes, making an array of dots on the surface that is essentially a "contact print" of the optical wave. The dots, shown in an atomic force microscope image in Fig. 6, are approximately 80 nm wide and 13 nm high, and are spaced on a square lattice at exactly 212.78 nm, as fixed by the laser wavelength.

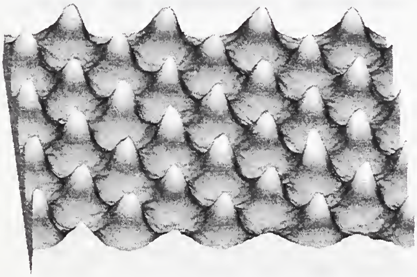


Figure 6. Atomic force microscope image of chromium nanodots formed by laser-focused atomic deposition.

The research represents another step in the development of a wide range of extensions and applications of nanostructure fabrication by laser focusing of atoms. A major advantage that this technique has over other methods such as electron beam lithography is the efficient, parallel nature of the fabrication – an entire square millimeter can be patterned in about 10 min. In addition, theoretical calculations show that the ultimate feature size could be as small as 10 nm or less. Eventual applications may include the fabrication of nanostructured materials or devices for microelectronics or micromagnetics, and the fabrication of length standards on a microscopic scale. (R. Gupta, J. McClelland, and R. Celotta).

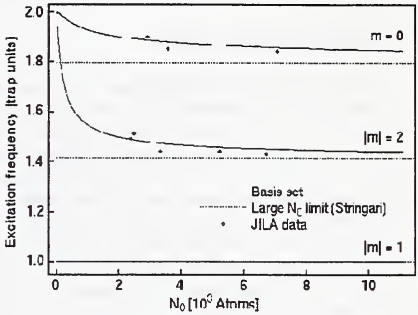


Figure 7. Computed excitation frequencies for the three lowest modes of the JILA ^{87}Rb BEC vs. number of condensate atoms; experimental results displayed as points. These are the frequencies of the free oscillations of the BEC that can be induced by modulation of the confining potential.

▪ **Quantitative Modelling of Atomic Bose-Einstein Condensates.** A new theoretical program for modelling the properties of zero-temperature, dilute atomic Bose-Einstein condensates (BECs) was initiated in the autumn of 1994, in collaboration with Groups at Georgia Southern University and Oxford University. Its initial focus was on developing practical methods for solving the nonlinear Schrödinger equation (NLSE) that describes the properties of a condensate in the mean-field approximation, and its scope has expanded to treat time- and temperature-dependent phenomena. Codes were developed to solve the NLSE for systems of up to a million atoms confined in the magnetic traps of experimental interest. Experiments at JILA first reported the first observation of BEC in the summer of 1995, and within the following year, the first experimental investigations of specific BEC properties had begun. The most detailed comparison of this theory with experimental data is displayed in Fig. 7, which shows the excitation spectrum of an ^{87}Rb condensate in the JILA trap. Our mean-field calculations predicted a maximum attainable condensate size of ~1500 atoms for the case of ^7Li, which appears to have been confirmed by subsequent measurements made at Rice University. Current effort is directed at solving mean-field theory at finite temperature and describing time-dependent BEC evolution, to provide general tools for modelling the "atom laser." (M. Brewczyk, K. Burnett, C.W. Clark, R.J. Dodd, M. Edwards, W.P. Reinhardt, and K. Rzazewski)

FUTURE DIRECTIONS

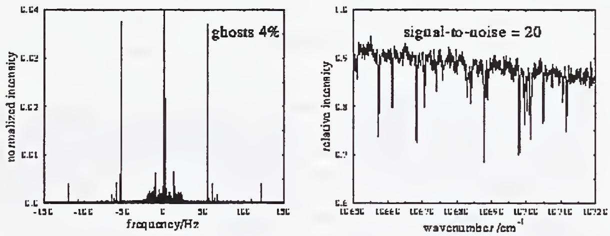
■ **Nanoscale Characterization.** The Electron Physics Group is developing a new program to characterize nanometer scale structures with atomic resolution measurements of their structure and electronic and magnetic properties. This program will provide the integration of nanofabrication efforts currently underway in the Group with characterization of the unique physical properties that result from the nanometer scale confinement. This integration will be achieved by combining the ongoing activity in laser controlled deposition of nanofabricated structures and the metal/semiconductor growth capabilities with the measuring of electronic properties of the various created structures. Properties such as energy level quantization and electrical transport will be measured. The new scanned probe instrument will operate over a wide range of temperatures, 1.5 to 300 K, to allow for the investigation of electron confinement in a variety of sized structures, as the energy level structure depends critically on structure size. The instrument will also have the capability to generate crossed magnetic fields up to 8 T to allow for a variety of magnetic measurements. Magnetic measurements will concentrate on the new magnetoresistive tunneling device structures, focusing on the role of electron spin in the tunneling process.

■ **SURF III Applications.** The SURF III upgrade will provide the Nation with a unified source-based absolute radiometric standard that spans the infrared through extreme ultraviolet spectral regions. The Optical Technology Division has made significant commitments to establish IR through UV radiometric facilities at SURF III, and we expect close coordination of our UV and EUV radiometry with their programs, and, in general, a more effective and efficient NIST-wide approach to radiometry as a whole. In addition, we are seeing the development of interest in scientific applications of synchrotron radiation outside the traditional EUV range that SURF has served: for example, the UV electroreflectance spectroscopy program initiated by the Biotechnology Division, and infrared microscopy. Thus we expect that the new radiometric focus on the IR, visible, and UV spectral regions will be accompanied by the development of other new measurement capabilities in those regions. ▫

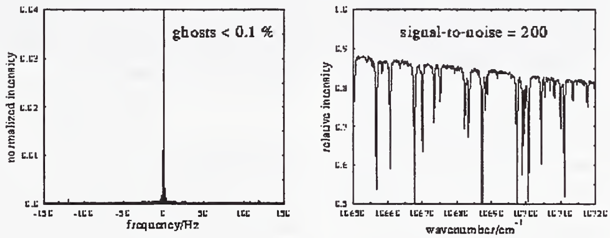
ATOMIC PHYSICS DIVISION

Spectra from the NIST IR-vis-UV Fourier transform spectrometer

Old data acquisition system:



New data acquisition system:



Overleaf

Spectra from the NIST IR-vis-UV Fourier transform spectrometer. We have implemented a sophisticated new data acquisition system for the IR-vis-UV Fourier transform spectrometer obtained in 1994 from Los Alamos National Laboratory. The figure shows the much lower noise and less sensitivity to the effects of non-uniform sampling achieved with the new design. The two plots on the left show the spectrum of a laser line before (top) and after (bottom) the new data acquisition system. The laser lines have an intensity of 1, and are the only real features in the spectrum. All other features are ghosts caused by sampling errors and have been virtually eliminated with the new system. The two plots on the right show the same region of a water vapor spectrum before (top) and after (bottom) the upgrade. The signal-to-noise has increased by an order of magnitude.

ATOMIC PHYSICS DIVISION

MISSION

The Division carries out a broad range of experimental and theoretical research in atomic physics in support of emerging technologies, industrial needs, and national science programs. Specifically, the Division:

- undertakes experimental and theoretical research on quantum processes in atomic, molecular, and nanoscale systems, especially on the spectroscopic and collisional properties of neutral and ionized atoms, and it explores their interactions in plasmas and with other forms of matter;
- provides measurement and data support for specific needs in such industrial areas as the processing of materials by plasmas and ion beams, commercial and residential lighting, optical materials characterization, spectrochemistry, x-ray analysis in medical and materials applications, and fusion-plasma diagnostics;
- contributes to the extension and refinement of the electromagnetic scale by linking standards in the visible with others in the x-ray and gamma-ray region;
- develops well-characterized atomic radiation sources and systems as secondary standards for wavelength calibrations and for vacuum ultraviolet (VUV) source radiometry;
- advances the physics of laser cooling and electromagnetic trapping, and the manipulation of neutral atoms and highly charged ions; and
- critically evaluates and compiles spectroscopic data and creates databases on wavelengths, energy levels, transition probabilities, and line widths and shifts, including x-ray wavelength tables.

These activities support many areas of advanced technology. For example, the detailed understanding of atomic processes in industrially applied plasmas is needed both for modeling purposes and diagnostics. As industry strives to optimize the widely applied plasma etching technique for semiconductors, the understanding of processes on the atomic level becomes critical for achieving the most efficient and reproducible operating conditions. Similar comments apply to surface cleaning by plasmas and to materials deposition by plasma sputtering techniques. Furthermore, process monitoring and modeling in plasma chemistry and spectrochemistry are on a fundamental level only possible with reliable radiation and collision data. Research in x-ray metrology and technology provides the underpinning for a broad range of industrial and medical applications, particularly materials and semiconductor research, as well as for space astronomy missions.

In response to the need for more accurate frequency standards and very high resolution spectroscopy, we develop advanced techniques for laser cooling and trapping of neutral atoms, an activity complementary to the trapped-ion projects in the Time and Frequency Division. These techniques of optical manipulation are also being developed for applications to new nanofabrication technologies and as a bio-optical research tool. Our theoretical work on ultracold collisions and atomic interactions provides key predictions for the properties of such systems.

The spectroscopic data we determine for highly stripped ions are used for fusion plasma diagnostics, such as the measurement of ion temperatures. The area of highly stripped heavy ions is also the natural laboratory in our fundamental quest for the ultimate atomic structure theory that properly considers all relativistic effects.

Our vacuum ultraviolet radiometry work with plasma sources provides miniaturized, calibrated radiation sources. Also, we develop spectroradiometers and, in a collaboration with the Optical Technology Division, interferometer-based refractometers, including precisely characterized line sources, for the characterization of materials used in deep-UV lithography applied in semiconductor fabrication.

ORGANIZATION

The Division is organized into five technical groups – atomic spectroscopy, quantum processes, plasma radiation, laser cooling and trapping, and quantum metrology – 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, other Laboratories at NIST, or with outside groups. The Division has currently 30 professional staff members, 6 postdocs, and 20 longer-term (>3 months) guest scientists.

CURRENT DIRECTIONS

■ **Generation of Atomic Reference Data.** We are producing atomic structure and collision data through innovative theoretical and experimental approaches, concentrating on neutral and low-ionization spectra as well as on highly ionized atoms of scientific and technological interest. On the theoretical side, we have developed sophisticated atomic structure codes and are calculating very accurate transition probabilities ($\approx 1\%$) for light atoms (atomic numbers <20) so that these theoretical results may serve as benchmarks for experiments and other theories.

A new theory developed by us for the electron-impact ionization of atoms provides reliable cross sections for polyatomic molecules, too, including those used in microchip etching containing fluorine and chlorine atoms.

On the experimental side, with our recently computer-automated electron beam ion trap (EBIT), we can now directly measure lifetimes of highly charged ions. A new metal-vapor vacuum arc injection source for the EBIT has broadened the range of elements (presently up to $Z=83$) and charge states ($Q>70+$) that we are studying. Our new Fourier Transform Spectrometer (FTS) has received its vacuum housing and is undergoing final tests with a sophisticated new data acquisition system, so that spectroscopic measurements will soon begin. With wall-stabilized arc sources, we are measuring numerous transition probabilities for LS-allowed and intersystem lines of neutral and singly ionized light atoms. Using our newly developed technique of photoassociation of ultracold atoms we have determined atomic radiative lifetimes with unprecedented accuracy.

■ **Data Compilations.** Data centers on atomic spectroscopy located in the Division are the principal resources for spectroscopic reference data in the world community. We are continuing the critical evaluations and compilations of wavelengths, atomic energy levels, and transition probabilities, partly supported by our own atomic data generation work, and we have started work on a new x-ray wavelength table. Also, we have put a large part of our comprehensive databases on the World Wide Web, and will update and expand this coverage.

■ **Ion-Surface Interactions.** With the new EBIT beam line we are investigating the atomic scale interaction of very highly charged ions ($Q \gg 30+$) with surfaces. The work is proceeding by a combination of (a) observations with x-ray and electron spectrometers during surface exposure to the ions, and (b) atomic force microscopy carried out subsequent to exposure. Also, we have demonstrated an approach to projection lithography using ions with extremely high charge states and are now studying this technique in detail.

■ **Optical Manipulation of Neutral Particles.** We study the physics of laser cooling, electromagnetic trapping, and other radiative manipulation of neutral atoms and dielectric particles. We are using these fundamental studies to develop applications to new kinds of physics measurements and processes, such as high resolution spectroscopy, atomic clocks, atomic collisions, atom optics, bio-molecular interactions, and atomic-scale and nanoscale fabrication.

We are developing comprehensive predictive theoretical models for atomic interactions and collision processes in cold trapped atomic gases. These are also used to model the properties of such gases and of Bose-Einstein condensates.

■ **Plasma Measurements.** The Division uses nonintrusive optical emission measurement techniques to determine the properties of radio frequency (rf) and inductively coupled plasmas. We are engaged in the detailed time- and space-resolved analysis of rf plasmas used in production-line plasma etching, and are also applying our experience in plasma work to develop and improve plasma radiometric source standards for the vacuum ultraviolet region.

■ **High Resolution X-Ray Probes of Geometrical and Electronic Structure.** Our capabilities in crystal characterization, dynamical diffraction modeling, multilayer production, and fundamental metrology of spectra and structure of crystals and multilayers continue to find wide application. Current work emphasizes x-ray studies of surfaces, thin films, and multilayer structures, using high performance dual ion beam deposition, multi-axis diffractometry, and theoretical modelling. We are currently providing methods for re-standardization of NIST supplied powder-diffraction standards. We are also actively involved with work in x-ray astronomy for future thin-shell, nested-mirror telescopes to reach higher into the hard x-ray region.

■ **Precision X-Ray and Gamma-Ray Measurements.** This work has three components: Optically-based measurements of a silicon lattice period (XROI), inter-specimen comparisons (delta-d), and Bragg-Laue diffraction studies using two-crystal instruments here and in Grenoble. The lattice comparator (delta-d) instrument measures the difference between the lattice spacings of crystal samples used for x- and gamma-ray diffraction with optically based (XROI) standards, e.g., comparison of crystal lattice spacings of samples from the standards laboratories that are making absolute lattice spacing measurements [Germany, Italy, Japan]. The joint NIST-ILL GAMS4 precision double-crystal spectrometer at the Institut Laue Langevin (ILL) measures gamma rays leading to the accurate determination of the neutron mass and the molar Planck constant, N_Ah. A second two-crystal transmission spectrometer at Gaithersburg with a 400 kV tungsten x-ray source is currently used to acquire emission spectra from transuranic elements to complement the wavelength tables project.

■ **Properties of Nanoscale Systems.** We develop and apply quantum mechanical methods for calculating the electronic states and optical properties of quantum dots, wires, and wells. Such systems have a wide variety of technological applications, including semiconductor lasers and advanced semiconductor devices. We have had much success in calculating the properties of quantum wire lasers and are also modeling images produced by scanning near-field optical microscopy, which offers the prospect for nanometer-scale optical metrology.

HIGHLIGHTS

■ **Precise Measurements of Iodine Lines for Laser Wavelength Standards.** Doppler-free spectra of molecular iodine provide a particularly convenient source of easily observed and highly reproducible lines for use as wavelength standards in laser spectroscopy. Precise wavelength values, however, have been reported previously for only a small number of lines. We have observed a selected group of 102 lines in a room temperature, 30 cm iodine cell by using Doppler-free, frequency modulation spectroscopy. The lines, which are uniformly distributed over the range 560 to 656 nm, were measured with our Fabry-Perot wavemeter with uncertainties of about 1 MHz (about 2 parts in 10^9). Excellent agreement is obtained for six of the lines that have been measured previously with comparable or better accuracy in other laboratories. Our results will be also useful as reference lines for the calibration of wavemeters and interferometers. (C. Sansonetti)

■ **Spectroscopy with the Large Fourier Transform Spectrometer.** We have implemented a much improved data acquisition system for our high-resolution IR-vis-UV spectrometer obtained in 1994. The new design replaces VME-bus computers with a more flexible PC-based data acquisition system, with much lower noise and less sensitivity to the effects of non-uniform sampling. The figure on the Division cover page compares spectra obtained with the old and new systems. The signal-to-noise ratio in the absorption spectrum has been increased by almost an order of magnitude, and the ghosts in the spectrum of the He-Ne laser have been virtually eliminated. We have installed the spectrometer in a vacuum tank, and expect to have the instrument fully operational by the end of 1996. (G. Nave, C. Sansonetti, U. Griesmann)

■ **Laser-Spectroscopic Tests of Wavelength Calibration in Fourier Transform Spectroscopy (FTS).** We have undertaken experiments to assess limitations of the wave number accuracy of FTS. In principle, the wave number scale of a FT spectrum can be calibrated by applying a simple multiplicative correction based on a single standard line. Measurements of precisely known lines of Ar II and ^{198}Hg made in several laboratories, however, have raised doubt about the reliability of this calibration procedure. In our experiments we illuminate a high resolution UV/VIS FTS with red light from a cw dye laser, UV light produced by frequency doubling this laser, and emission from a ^{198}Hg electrodeless discharge lamp. Light from these sources is combined in an integrating sphere. Regardless of the absolute calibration, the ratio of the wave number of the UV laser light to that of the red light should be exactly 2. We have observed that deviations from 2 as large as several parts in 10^8 can easily result from minor misalignment of the interferometer that normally would go unnoticed. Using the ratio of the UV and red laser wave numbers as a diagnostic, we are working on alignment procedures that will ensure a calibration error less than one part in

10^8. We are also remeasuring wavelengths of ^{198}Hg, which are recommended by the CCDM as an optical realization of the meter, by locking the red laser to an iodine line that has been precisely measured by laser spectroscopy and using the red and UV lasers as calibration standards. (C. Sansonetti and D. Veza with M. Salit and J. Travis of CSTL)

■ **High Resolution Measurements of Atomic Spectra for Space Astronomy.** Spectral analyses have been completed for elements of interest for the interpretation of spectra obtained with the Hubble Space Telescope (HST) of chemically peculiar stars. The over-abundance (factors of 10^4 or 10^5) of certain heavy elements in the atmospheres of such stars continues to be a major puzzle of stellar astrophysics. In this connection, we completed a new energy-level analysis of Hg II from observations with our 10.7 m, normal incidence vacuum spectrograph. We also calculated oscillator strengths for this ion. We have provided *rapid response* to several requests for data from HST investigators. For example, our new measurements of Bi I, II, and III in the far UV will be used to establish the abundance of Bi in the star HR7775. Similarly, we made an accurate measurement of a Pb III line near 155 nm, which will be used to determine the abundance of Pb in the chemically peculiar star chi Lupi.

We have also measured the wavelengths of 473 Fe II lines between 93 nm and 200 nm. Lines were identified in high-resolution grating spectra taken with the 10.7 m, normal incidence grating spectrograph, and precise Ritz wavelengths were derived from energy levels obtained from ultraviolet, visible, and infrared Fourier transform spectra. The uncertainties of the wavelengths span a range from 9×10^{-6} nm to 7×10^{-5} nm (0.005 cm^{-1} to 0.02 cm^{-1}). The data will be useful for both calibration of laboratory spectrometers and also for analyses of astrophysical spectra. (J. Reader, C. Sansonetti, G. Nave)

■ **Observation of Spectra of Highly Ionized Atoms.** We have continued our studies of spectra of highly ionized atoms of importance for tokamak diagnostics. We completed measurements of spectra of highly-ionized rare earth elements from Gd^{37+} to Hf^{46+}, generated by focusing a single beam from the Glass Development Laser at the University of Rochester onto flat metallic targets. The results will provide improved understanding of the iron, cobalt, and copper isoelectronic sequences and aid in the evaluation of calculations of relativistic effects in heavy ions. (J. Reader)

■ **New Critically Compiled Atomic Energy Level and Wavelength Data and Enhancement of the Atomic Spectroscopic Database.** We have completed a large one-volume compilation of *Spectral Data for Highly Ionized Atoms*, including wavelengths, energy-level classifications, and transition probabilities for the elements Ti through Cu, and Kr and Mo. Other recently completed or ongoing compilations of energy-level and wavelength data include all spectra of Ar, Zn, and Ga, and of the lighter elements Be, B, F, and Ne. As the new compilations are completed, the data are being added to our Atomic Spectroscopic Database on the Internet. Hypertext links to references and ionization energies for particular spectra have been added, and other improvements of the interactive selection/retrieval procedures have been made. A bibliographic database on atomic energy levels and spectra covering the period since 1988 has also been prepared for the NIST Physics Lab Web site. (W.C. Martin, J. Sugar, A. Musgrove with G. Dalton, SRD Program)

■ **Atomic Transition Probability Data Compilations Published.** A new data volume "Atomic Transition Probabilities of Carbon, Nitrogen, and Oxygen, A Critical Data Compilation" has been published in 1996. This 530 page book contains critically evaluated numerical data for about 13,000 allowed and forbidden transitions. Analogous work on He, Li, and Na is nearing completion. An expanded bibliographic database on atomic transition probabilities, which contains over 6600 references, is now accessible on the NIST Physics Lab WWW site. (W.L. Wiese, J.R. Fuhr, D.E. Kelleher, H. Felrice)

■ **Collision Rates in Bose-Einstein Condensates.** Atomic collisions are crucial in determining the evaporative cooling rates that lead to nanokelvin temperatures and Bose-Einstein condensation of cold atomic gases of ^{23}Na or ^{87}Rb atoms; collisions also control the stability and lifetime of condensates. Photoassociation spectra of trapped atoms permit the most accurate measurement of scattering lengths and other atom interaction parameters that characterize evaporative cooling kinetics and condensate properties. We have therefore constructed quantitative quantum mechanical computational methods for interpreting such spectra. Using experimental data provided by the Laser Cooling Group, we have obtained a very accurate value for the scattering length of the Na ground state $F = 1$, $M = -1$ hyperfine component. We have also calculated the collisional relaxation rates for various combinations of hyperfine components of ^{23}Na or ^{87}Rb atoms in the limiting case of weak magnetic trapping fields. Our results are consistent with recent observations on ^{23}Na and ^{87}Rb condensates. (P.S. Julienne, F. Mies, E. Tiesinga, C.J. Williams)

■ **Complex Quantum Nanostructures.** As semiconductor nanotechnology develops, the nanostructures being fabricated become more complex, with complicated geometries and strong coupling between structures. For example, complex multilayer quantum dot structures, called quantum dot quantum wells in analogy with quantum well structures, can be made by chemical growth techniques. Such structures may be viewed as a generalization of the usual concept of an atom or molecule, whereby the energy states and optical properties are controlled by the design of the structure. We made a special effort to assess the effect of electron-hole correlation in quantum dot quantum wells and T-shaped quantum wires. We find that simple, effective mass models for the single-particle states, combined with a full three-dimensional treatment of pair-correlation, provide accurate results for pair state transition energies in these structures. Proper inclusion of the pair interaction is critical. For T-shaped quantum wires, we find that the confinement is much weaker than previously inferred from the experimental data. The confinement in these structures is not strong enough to quantum confine the electrons and holes. Rather, there is significant pair interaction and correlation in all directions, which must be taken into account in future experimental attempts to fabricate T-shaped structures with enhanced binding. (G.W. Bryant, P.S. Julienne)

■ **Theory of Near-Field Optical Microscopy.** The diffraction limit in optics, once considered the ultimate resolution of any optical system (such as the light microscope), can be overcome by exploiting the properties of the "near" optical field. However, a serious drawback of near-field optics is the complexity of the near-field interaction between probe and sample. We are working in collaboration with the Optical Technology Division to develop near-field scanning optical microscopy (NSOM) as a nanoscale metrology tool. We are developing theoretical models for NSOM that fully account for the far field propagating through the probe that is connected to the light source or detector, the near fields that couple the sample to the probe, and the near fields that couple parts of the sample together or the sample to the substrate. In our first effort we have modeled the NSOM images obtained by probing nanochannel glass arrays. We include a Bethe-Bouwkamp model for the tip, exact calculations for the bulk photonic modes of the nanochannel glass, and full treatment of the tip/sample coupling at the surface, to calculate the optical intensity gathered by the collection optics. With this model we can accurately reproduce the observed NSOM images. Our theory allows us to directly determine the sensitivity of the images to tip/sample separation, probe polarization, aperture size, and other details of the probe fields. This information is critical for developing the understanding of NSOM metrology needed to interpret images and extract information from them. (G.W. Bryant and P.S. Julienne with L. Goldner and E. Shirley of Division 844)

■ **Fundamental Constants.** Work on the new least squares adjustment of the fundamental constants to produce CODATA recommended values is progressing well and is expected to be completed in FY97. As part of this project, we have carried out a thorough review of the theory of the electron anomalous magnetic moment, the muon anomalous magnetic moment, and the hyperfine splitting in muonium. This theory is critical for the determination of the fundamental constants from the corresponding measurements. Also, there is a bibliographic database on fundamental constants available on the Physics Laboratory WWW server. (P. Mohr and B. Taylor of Division 840)

■ **Accurate Electron Impact Ionization Cross Sections for Molecules and Radicals.** We have developed a new theory for calculating electron-impact total ionization cross sections for atoms and molecules. Our Binary-Encounter Bethe (BEB) theory uses orbital energy (in lieu of the binding energy), kinetic energy, the occupation number of each molecular orbital in the ground state, and an analytic formula to generate total ionization cross sections of molecules. The resulting cross sections are in excellent agreement (within 10%) with known, reliable experimental data from threshold to a few keV in incident energies, for a wide range of molecules, H_2 through SF_6. The BEB theory works as well for radicals. Cross sections for over 50 molecules and radicals have been calculated, particularly those for air pollutants and plasma etching of semiconductors, as well as hydrocarbons in tokamaks. These data will be made available to fusion plasma and plasma etching modelers through the Physics Laboratory WWW server. (Y.-K. Kim, M.A. Ali, W. Hwang, and E. Rudd)

■ **Corrections to Relativistic Atomic Calculations.** We have found that relativistic "multi-configuration" wave functions sometimes do not have the correct nonrelativistic limit. This results in inaccurate transition probabilities for weak or nonrelativistically forbidden transitions. This incorrect limit has been overlooked in the past, causing misleading published results. We are now developing a general method to correct the situation that will apply to a wide range of configurations. Such a method will lead to more reliable transition probabilities for spin-forbidden transitions, e.g., the $2s^2\ {}^1S_0 \rightarrow 2s2p\ {}^3P_1$ transition of Be-like ions. (Y.-K. Kim and J.-P. Desclaux)

■ **Nanoscale Surface Modification with the Highly Charged EBIT Ion Beam.** Our electron beam ion beam trap (EBIT) has been equipped with an ion beam extractor to provide ions with extremely high charge states ($Q > 40+$) for use in ion-surface interaction studies. The ion beam line delivers continuous and short-pulse beams with orders of magnitude more flux than that of the only other EBIT beam line in the world. We are presently developing novel methods of nanoscale surface modification. A molecular dynamics simulation of the hypothesized ion-induced surface Coulomb explosion has been carried out (Fig. 1), and laboratory data are being collected from a series of experiments (L.P. Ratliff, J.D. Gillaspy, and D. Parks)

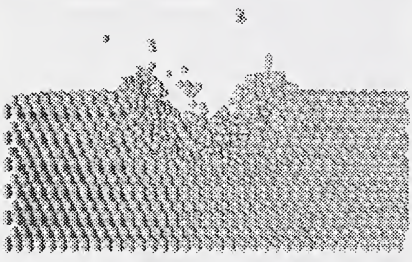


Figure 1. Molecular dynamics simulation of a surface Coulomb explosion at the surface of a silicon lattice (shown in cross section as a crater is being formed). The motion is tracked in sub-femtosecond time steps, as nearly 35,000 atoms interact with each other via realistic potentials. An explosion such as this is believed to be initiated by a single incident highly charged ion.

■ **Metastable Atom Lithography.** In a collaboration with researchers from the Electron and Optical Physics Division and Harvard University, we have provided the first demonstration of a new type of microlithography in which excited atoms of noble gases are used to pattern silicon. The technique relies on the local deposition of the atoms' internal energy, stored in an excited metastable state, to expose an ultra-thin, self-assembled monolayer resist. After projecting the metastable atoms through a grid and onto the resist, chemical processing was used to produce a high-resolution image of the grid in silicon. The 100 nm edge roughness of the image (Fig. 2) was limited by the grid, not the metastable exposure process itself. The resist is sensitive to exposure by as little as about one metastable atom per resist molecule. (J.D. Gillaspy, S.L. Rolston and W.D. Phillips with J.J. McClelland of Division 841)

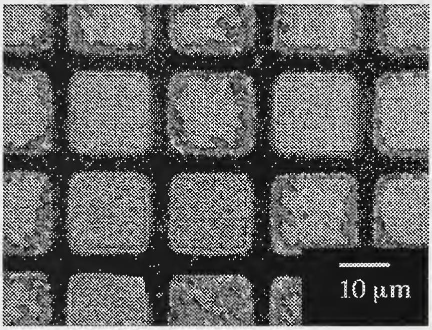


Figure 2. This grid-pattern in silicon was the first demonstration of metastable atom microlithography.

■ **Lifetime Measurement of Magnetic Dipole Transitions with EBIT.** We have measured the lifetime of a magnetic-dipole transition in Xe^{+32} by using a novel technique, the magnetic trapping mode of EBIT. The measured lifetime is of the order of milliseconds. Such long lifetimes of highly charged ions have been observed previously only by using storage rings or accelerators. (F.G. Serpa, J.D. Gillaspy)

■ **Characterization of the GEC RF Reference Cell.** We have observed the spatially resolved optical emission (OES) and laser induced fluorescence (LIF) from a pure SF_6 discharge. SF_6 and other fluorine containing gasses are used in the etching of silicon and tungsten. Because SF_6 is an electronegative gas, large numbers of negatively charged ions exist within the plasma. The results of this investigation, combined with electrical measurements and ion-energy mass spectrometry, have proven to be a more comprehensive and consistent characterization of 13.56 MHz discharges in SF_6 than has been possible from previous, single-technique measurements. These results should prove useful both in validation of theoretical models for SF_6 discharges and in the interpretation of other experimental results. This is primarily due to the fact that these measurements were performed using the GEC reference cell, which exists in many other laboratories and for which proven procedures have been developed. The OES and LIF spatial intensity distribution profiles exhibit sharp maxima in narrow regions in front of the electrodes, consistent with a constricted sheath. The vertical OES and LIF profiles exhibit secondary maxima, suggestive of a double-layer formation, which has been previously predicted.

We have also developed a new plasma uniformity monitor for axially symmetric plasmas. This device is being tested on the GEC rf reference cell, but is intended for use on commercial etching systems which have limited optical access. (E. Benck, J. Roberts, A. Schwabedissen)

■ **Characterization of an Inductively Coupled Plasma (ICP) Cell.** Our new inductively-coupled rf-powered version of the GEC rf reference cell is fully operational. This new class of high density, low pressure plasma sources is becoming increasingly important to meet the increasing demands of reducing the dimensions of etched structures. Langmuir probe measurements have demonstrated the effects of a variety of different feed gasses on the electron density and energy distribution function within the inductively coupled plasma (ICP), and time-resolved optical emission spectroscopy has been used to study the sheath region adjacent to an rf-biased electrode in an argon discharge. We have found that, unlike capacitively coupled discharges such as the GEC reference cell, rf biasing of electrodes in an ICP provides control, independent of the plasma production, of the ion energies involved in the etching process. (E. Benck, J. Roberts, A. Schwabedissen)

■ **Accurate Atomic Transition Probability Measurements.** Atomic transition probabilities and branching fraction data are of importance to industrial applications of plasma physics (e.g., the lighting industry and plasma processing), astrophysics, and basic atomic theory. Atomic structure calculations for light elements have recently achieved an accuracy that approaches that of the best available experimental data. In response to this development, we have improved the uncertainty of our measurements (better than 10%) by the use of modern experimental techniques such as photon counting and Fourier transform (FT) spectrometry. We have measured relative transition probabilities of O I, and branching fractions of weak intersystem lines of N II, Ne II, and Fe I, by observing spectral lines emitted by a wall-stabilized arc and from a hollow cathode lamp. (J.M. Bridges, U. Griesmann, W.L. Wiese)

■ **Development of New Infrared Source.** The Atomic Physics and Optical Technology Divisions have collaborated on a project resulting in the development of a new, brighter IR source. This new source yields better signal-to-noise ratios, and therefore higher accuracy, in IR measurements. The source is a stabilized argon arc, which has been characterized in the spectral range from 1 μm to 20 μm. Its radiance was calibrated and found to be approximately equal over much of this range to that of a 10,000 K blackbody. A high-resolution spectrum taken with a FTIR instrument shows mostly line emission below 5 μm, and pure continuum between 5 μm and 20 μm. The stability and geometrical properties of the radiance were determined, as well as its dependence on pressure and current. As a result of this project, this source is now being used in calibrating IR detectors, as well as in projects aimed at advancing IR measurements and technology. (J.M. Bridges and A. Migdall of Div. 844)

■ **Deep-UV Refractive Index Measurements.** We have teamed with the Optical Technology Division to make high-accuracy, deep-UV index-of-refraction measurements of materials considered for use in the optical components of photolithography steppers for future-generation IC fabrication. This is part of a collaborative project with the MIT Lincoln Laboratory and SEMATECH. To meet the immediate need for accurate values of the index of refraction of fused silica at 193 nm, we have upgraded a precision refractometer, including precisely characterized UV line sources, to enable minimum-deviation-angle, refractive-index measurements, accurate to 1 part in 10^5, with a temperature control of 0.1 °C. The system also enables the determination of the temperature coefficient of the index. These measurements are needed to design the transmissive optics for the steppers for 0.18 μm minimum-feature-size IC fabrication (1 Gbit DRAM), which is scheduled by the SIA roadmap for production by the U.S. semiconductor industry beginning in 2001. We have begun these measurements on fused-quartz samples provided via SEMATECH by several of the potential suppliers. We will also make similar measurements on calcium fluoride and other deep-UV optical materials being considered for 0.18 μm and shorter wavelength lithography. (J.H. Burnett, J.R. Roberts)

■ **Bragg Scattering from Optical Lattices.** Atoms laser cooled in intersecting laser beams become trapped in the periodic light-shift potentials created by the interference of the laser beams. This optical lattice holds the atoms at precisely periodic locations, as in a solid crystal, but with a lattice spacing on the order of optical wavelengths.

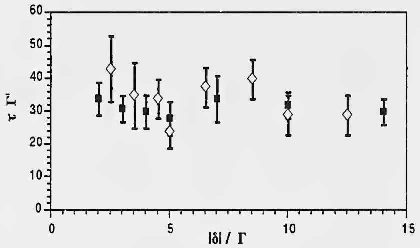


Figure 3. The product of the photon scattering rate Γ' and the cooling time constant τ for various lattice laser detunings in 1-D. The filled squares are experimental results, and the open diamonds are quantum Monte Carlo simulations for the same parameters.

Just as x-rays Bragg-reflect from regular crystal planes, light tuned near an atomic resonance can Bragg-reflect from our optical lattices. Among the properties of this Bragg scattering are that it depends sensitively on satisfying the wavelength and angle conditions for coherent addition of the waves reflected from successive atomic planes and that its amplitude depends on how well localized to those ideal planes the atoms are. Using this latter fact, we have studied the time-dependent evolution of atomic motion in the optical lattice. For example, for a given optical lattice, atoms with a higher temperature will be less tightly localized at the precise lattice sites, the periodically located potential minima, and will give less Bragg scattering. By measuring the Bragg scattering as a function of time after the lattice is switched on, we have measured for the first time how fast atoms are laser cooled. We find that the cooling rate is proportional to one parameter, the photon scattering rate, over a wide range of lattice laser detunings, shown in Fig. 3.

In both 3-D and 1-D we find this proportionality, although the cooling is about six times slower in 3-D. In 1-D, where calculations are possible, we find essentially perfect agreement with our fully quantum treatment of both internal and center-of-mass atomic motion. Although this is satisfying, the result is in disagreement with the semiclassical picture of laser cooling that has guided the thinking of the community since 1989. How to provide a new physical picture consistent with these as well as earlier results, and how to understand the differences between 1-D and 3-D remain open questions. (G. Birkl, G. Raithel, M. Gatzke, S. Rolston, I. Deutsch, W. Phillips)

■ **Coherent Atomic Wave Packet Motion.** We use Bragg scattering to study induced and driven oscillations of atoms in an optical lattice. By suddenly increasing the intensity of the lattice laser beams, we compress the trapped atoms toward the minima of the potential wells. The atoms then oscillate about the potential minima, so that the average atom cloud "breathes" at twice the oscillation frequency. We see this as an oscillating Bragg signal that decays due mainly to the anharmonicity of the potential wells, as seen in Fig. 4.

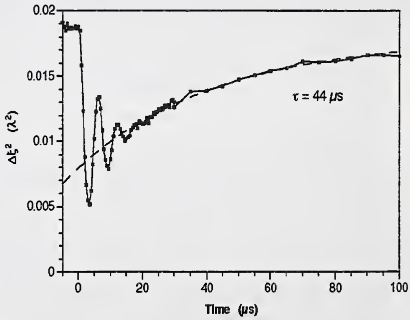


Figure 4. Oscillations of the mean square displacement $\Delta\xi^2$ of atoms from the potential minima. The oscillations follow a sudden compression where the intensity of the lattice light is increased by a factor of 4. The oscillations decay quickly due to anharmonicity while $\Delta\xi^2$ returns to equilibrium more slowly due to laser cooling.

In addition to such sudden compression, we have induced oscillations by continuously modulating the intensity of the lattice beams. This parametric driving of the atomic motion produces results similar to quadrature squeezing of light, in that the position and momentum spreads of the atoms are modulated periodically and in quadrature, although we have not yet achieved squeezing below the standard quantum limit. (S. Rolston, G. Raithel, G. Birkl, W. Phillips)

■ **Atomic Fountain Clock.** In collaboration with the Time and Frequency Division we have built and installed an atomic fountain frequency standard operating with laser-cooled Cs atoms. This standard is just beginning operation and we are using it to study optimal ways of launching, cooling, and probing the atoms. Cooling to a few microkelvin is a pre-requisite for a good fountain clock, but atoms even colder than this would be a significant advantage. Among the strategies being studied for further temperature reduction are adiabatic expansion in optical lattices, and sub-recoil Raman cooling. (C. Ekstrom, W. Klipstein, M. Golding, S. Rolston, W. Phillips)

■ **Optically Controlled Biological Collisions.** Collision and adhesion of biological particles such as cells and pathogens are a process of fundamental interest in biomedicine. We use optical tweezers to hold and manipulate particles, producing controlled collisions for quantitative study of adhesion. We coat glass spheres with viruses and collide them with red blood cells, measuring the sticking probability in the presence of chemicals that inhibit adhesion. In collaboration with the Whitesides group at Harvard, we measure inhibition constants that were unmeasurable by any other techniques. (K. Helmerson, R. Kishore, W. Phillips)

■ **Bose-Einstein Condensation.** Building on the success of BEC in the Quantum Physics Division, we have begun an effort to Bose condense Na atoms as a source of coherent atoms for atom optics experiments. Our approach is a hybrid of successful efforts at JILA and MIT. We load cold atoms into a magneto-optical trap (MOT) using the Zeeman slowing technique first developed in our group. Co-located with the MOT is a time-orbiting-potential (TOP) trap, modified from the JILA design to make transfer from the MOT more efficient in phase space. As of this writing, we have trapped about 5×10^8 atoms in a MOT cloud about 1 mm in diameter, a density that should be sufficient for evaporative cooling and condensation of a cloud with close to a million atoms. (R. Thompson, A. Steinberg, M. Gatzke, G. Birkl, S. Rolston, K. Helmerson, W. Phillips)

■ **Photoassociative Spectroscopy.** When two atoms collide at very low velocity in the presence of a light field, they can absorb a photon during the collision and become bound together as an excited molecule. This photoassociation of ultracold atoms allows the study of molecular states that are otherwise inaccessible. In particular, we can study "purely long-range" molecular states in which both the inner and outer turning point of vibrational motion are larger than tens of atomic units, well beyond the range of exchange and chemical forces. Such molecules are particularly easy to understand because their properties are determined almost entirely by long-range dipole-dipole forces. By studying the spectra of such molecules, we have obtained the best measurements of the ground state scattering length and the *atomic* radiative lifetime for Na, and we have seen for the first time the effect of radiative retardation on a molecular spectrum. A portion of such a molecular spectrum is shown in Fig 5. Because the excitation probability of the various rotational states is determined by corresponding angular momentum partial-wave ground state scattering wavefunctions, this spectrum allows us to pinpoint the location of the s-wave nodes and therefore the scattering length. This, in turn, determines both the elastic collision cross section at low energy and the mean-field interaction energy, quantities of central importance in the study of Bose-Einstein condensation of atomic gases.

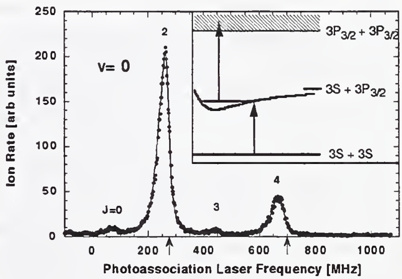


Figure 5. Spectrum of the vibrational ground state of the 0_g^- potential of singly excited Na_2. Detection is by ionization of the excited molecule, as shown in the inset. The relative heights and absolute positions of the peaks give information about the atomic radiative lifetime, scattering length, and about radiative retardation effects.

The molecular binding force between the atoms depends on the same dipole matrix element that determines the atomic radiative lifetime of the resonance level, so that measurement of the spacing between the vibrational levels allowed us to determine the atomic lifetime to an accuracy of 0.1%, the best Na lifetime determination ever. Because the fields binding the atoms propagate at light speed over distances that are unusually large for molecules, there is a shift in the energy levels from the retardation. We measure the shift of $\upsilon = 0$ to be 122(10) MHz, compared to the calculated shift of 121 MHz. (P. Lett, K. Jones, L. Ratliff, W. Phillips)

■ **Three Tunable X-Ray Spectrometers Delivered to NASA Programs.** NASA missions in x-ray astronomy required widely tunable monochromatic x-radiation for pre-flight calibrations and subsystem development. The AXAF version of one of these instruments, covers the range from 0.3 keV to 12 keV; it was installed at Marshall Space Flight Center (MSFC) in late 1995. This instrument uses a MSFC supplied rotating anode source and provides monochromatized beams at the entrance to an 875 m long vacuum whose exit chamber contains the AXAF telescope. The NIST monochromator may be visited at the URL: http://wwwastro.msfc.nasa.gov/xray/xraycal/xssrr/dcm/. (J.-L. Staudenmann, L.T. Hudson, A. Henins)

■ **Spectrometric Standardization of Mammographic X-Ray Sources.** The NIST curved-crystal x-ray spectrometer has now been tested in a variety of medical research environments. This device (patented and licensed for commercial development) provides high voltage calibration and spectral characterization for mammographic x-ray sources in support of diagnostic radiation quality requirements. A significantly overdetermined calibration is obtained using the well-known location of K absorption edges of a few metal foils. Data fitted to the formal dispersion function give residues below 0.1 kV, i.e., well below currently understood clinical significance. Additionally, the acquisition of the spectral distribution allows improved modelling and refinement of the mammographic paradigm. In the framework of a supporting grant from the Army's Breast Cancer Research Program, co-operative studies have begun at the Center for Devices and Radiological Health (a component of the Food and Drug Administration), the University of California-Davis Medical Center, and Radcal Corporation, the commercial licensee. Through Radcal's efforts, the first commercial model (aimed at the research market) is to be available by the end of 1996. A summary publication has recently appeared in the journal Medical Physics. (L.T. Hudson, R. Deslattes, A. Henins)

■ **Lattice Changes in Si Epilayers and Si Substrates.** Certain high-performance microprocessors are fabricated using epitaxially deposited, thin Si layers grown on highly doped Si wafers. In at least one case, it was found that material from different vendors gave differing device yields, although all sources met stated electrical criteria and appeared consistent using the manufacturer's current metrology toolbox. We examined substrate lattices using high-resolution lattice parameter comparison techniques developed in the Group. The measurements showed considerable variation (fractional changes of up to 5×10^{-5}) among the sources and even a rather large difference between nominally identically processed samples from 20 cm and 15 cm boules. In a second set of measurements, the lattice constant of the epilayer was measured with respect to that of the substrate using conventional high-resolution double-crystal diffractometry. Fractional differences obtained in these measurements range from 2×10^{-5} to 1×10^{-4}. The two measurements can be combined to obtain the lattice parameter of the epilayer itself. There is some indication that the lattice parameter differences seen here (somewhat smaller than can be resolved by conventional diffractometry) correlate with device yield although the needed control studies have not yet been undertaken. (R. Deslattes, J. E. Schweppe, L.T. Hudson, A. Henins)

■ **A New X-Ray Optics Geometry for Powder Diffraction.** The need to recertify powder-diffraction standards required realization of accurate powder-diffraction measurements with a parallel x-ray beam. In addition, accurate determination of the diffraction angle zero demands an instrument operable in mirror symmetric configurations. These geometric constraints and the accuracy needs led us to construct an entirely new apparatus for the measurement. The restriction to parallel beam geometry leads to a significant loss in signal levels in comparison with conventional (focussing) geometries. One solution would be to use a synchrotron radiation source. This clearly addresses the intensity problem but requires separate determination of the input wavelength and entails establishing a good metrological environment on the floor of an accelerator facility. In a recent development, we have been able to obtain incident beam intensity from a conventional (2 kW) diffraction tube comparable to that available at a synchrotron radiation powder-diffraction beamline. The key to this development is a newly realized combination of a graded spacing multilayer paraboloid with a flat multilayer optic having a spacing near the mean value of the graded spacing mirror. The beam from this mirror pair has a divergence of about 107 μrad and provides a photon rate exceeding 1 GHz at the sample. The divergence of this beam in the orthogonal direction is restricted to 10 mrad. Preliminary powder diffraction scans indicate good peak to background ratios, symmetric profiles, and counting rates sufficient to proceed with the needed measurements in the more benign environment of the Gaithersburg laboratories. As reported in a recent publication, we have shown that the lattice spacing for powder Si can be measured with our present apparatus with a relative uncertainty at the 2×10^{-6} level. This work is supported in part by the NIST Standard Reference Material Program. (J.-L. Staudenmann, L.T. Hudson, A. Henins, R. Deslattes)

■ **Field Emitter Arrays for Flat Panel Displays.** Field emission displays (FEDs) are being pursued by US companies as a leap-frog flat panel technology that has the potential of increasing the US flat panel display market share from the current 0.4%. The advantages of FEDs over other flat panel display technologies include CRT-like display quality, a wide operating temperature range, and low power consumption. Research on the physics of field emission cathodes in support of FEDs is performed with funding by the ATP program to provide technical support to two ATP-funded companies: FED Corp. and SI Diamond Technologies, Inc. For FED Corp., we provided simulation of electron emission and electron trajectories from gated field emitter arrays and experimental testing of FED Corp's displays. For SI Diamond, we performed electron trajectory simulations and will fabricate and characterize well-controlled diamond-like-carbon thin films. Additional support from DARPA has produced the fabrication of field emitter cathodes with integrated lenses coplanar to the gate electrode for collimating electron beams from tips of gated field emitter arrays. Linear planar lens electrodes on both sides of a line of emitters have been demonstrated to provide focusing by application of appropriate voltages. The chips were tested in a high vacuum chamber where the emitted electrons were accelerated to a phosphor screen anode parallel to the chip. The resulting image was magnified in a telemicroscope and captured by a CCD camera. With focussing, the resulting line image was less than 0.035 mm wide at 10 mm to 20 mm from the anode, while the unfocused image is about 100 times larger. This is the first demonstration of electron beam focusing from field emitter arrays with an integrated planar lens design in a well documented study with calibrated image registration. (C.M. Tang, J. Pedulla)

FUTURE DIRECTIONS

■ **Determination of Atomic Properties.** We will continue to determine accurate structure data for those atoms and atomic ions that are of major interest in industrial and scientific applications, and we will utilize a variety of advanced experimental and theoretical approaches.

With our Electron Beam Ion Trap facility we shall carry out visible, near UV, and x-ray wavelength and lifetime measurements for highly charged ions. With our new FTS instrument, we shall pursue analyses of complex spectra and branching ratio measurements, reaching from the UV deep into the infrared with greatly improved data acquisition and analysis. This will provide, for example, reliable data needed for the development of new sources for high-efficiency lighting. With precisely characterized plasma sources, we shall determine transition probabilities for lines of light elements with much increased accuracy, making use of state-of-the-art data acquisition techniques and the capabilities of the new FTS instrument.

■ **Critical Evaluation, Compilation and Dissemination of Atomic Data.** Our critical data compilation work will proceed vigorously on tabulations of spectroscopic data, i.e., wavelengths, energy levels, and transition probabilities, for elements of atomic numbers $Z = 1$ through 36, and on the establishment of a comprehensive spectroscopic database. Our new tabulations will contain more accurate as well as far more extensive data for each spectrum than the older NIST tables of the 1950s and 1960s, which are still the standard reference data works for a number of these elements. We will include these new compilations in an enhanced database for the Internet, with the principal dissemination channel being the NIST Physics Laboratory World Wide Web (WWW) Site. In a multiyear effort we will undertake a new, all-Z tabulation of x-ray wavelengths to replace the current 35 year old tables.

■ **Nanoscale Systems.** We are developing the techniques and large-scale computational algorithms needed to study nanoscale systems. We will extend our calculations of the optical properties of nanostructures to include the effects of valence-band mixing. This will allow us to accurately model the full range of complex nanostructures with a wide range of sizes and confinement geometries by use of one common model for band states. High-density arrays of strongly coupled, close-packed quantum dots can now be made. These arrays are needed for real optical device applications to provide the high-density of optical elements required to realize the advantages of optical nanostructures. Such systems show significant dot-to-dot energy transfer. We will begin to model the properties of a new class of materials systems, including the effects of intradot band states, interdot tunneling, and inter- and intradot interactions.

On the EBIT ion extraction facility, we will install an *in situ* (vacuum) atomic force microscope and UHV surface-preparation chamber at the end of the beam line. This will allow us to directly study the nanoscale effects of highly charged ions on insulating and semiconducting surfaces without atmospheric oxidation. Measurement of the physical and electronic changes under such well-controlled conditions is a necessary first step towards using highly charged ions as a possible nanoscale lithography tool.

■ **Laser Cooling and Atom Manipulation.** Experiments are underway to achieve Bose-Einstein condensation in our Na trap, with the ultimate goal of obtaining coherent extraction of the atoms from the Bose condensate. The development of techniques to coherently extract and measure the properties of a beam of atoms with a coherence length longer than the spatial extent of the condensate in the trap is of fundamental importance in the realization of the atom laser. We will also collaborate with the Electron and Optical Physics Division to construct theoretical models for the atom laser. In addition, we will begin to explore the use of photoassociation spectroscopy lineshapes as a diagnostic in the approach to BEC. A combination of ultracold-collision experiments and theoretical analysis will refine measurements of the scattering lengths and collision rates relevant to BEC. We plan on continuing our studies of optical lattices by creating them with a laser tuned very far off resonance so that we can study quantum transport such as tunneling and diffusion in a three-dimensional lattice system with essentially no damping. The optically controlled collision technique developed for the optical tweezers will be applied to study the adhesion of sialyl-Lewis-X to selectin and its inhibition. This adhesion mechanism is fundamental to a number of important biological systems and has potential applications in preventing the spread of cancer and in the development of highly effective contraceptives.

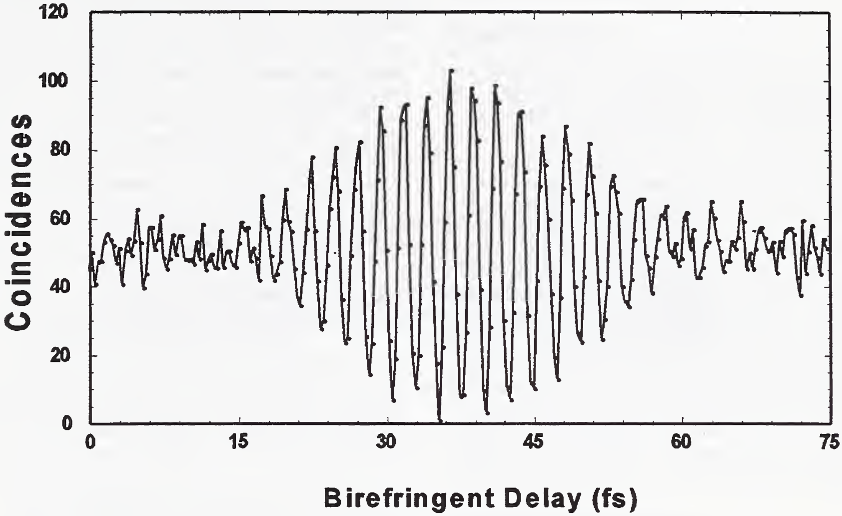
■ **Metrology.** In a new 5 year NIST competence project, which was awarded jointly to the Precision Engineering Division of MEL and to our Division, we have embarked on a three-pronged program of combining Michelson, Fabry-Perot, and x-ray interferometry to achieve length displacement metrology below the nanometer level over the range of a few micrometers to several decimeters. Well-documented periodicities and other systematic shortcomings in the individual interferometric techniques will pose significant challenges to this goal, but should be overcome by utilizing the three approaches in a mutually reinforcing manner.

We are collaborating with the Time and Frequency Division on the development of a Cesium-fountain atomic clock and frequency standard. A prototype fountain has been assembled in our laboratory and is undergoing extensive testing. We will soon study a new cooling method and other physics-related issues, which – if successful – will be incorporated into the Boulder standard. We are continuing our VUV radiometry source-standards development, as well as, the refinement of existing sources.

We are collaborating with the Optical Technology Division to develop near-field scanning optical microscopy as a measurement tool for the optical properties of materials at the scale of a few nanometers. We will continue to develop computational models of probe-sample interactions and optical images to better understand contrast mechanisms and resolution.

■ **Plasma Measurements.** In the diagnostic work on industrially applied plasmas, we will pursue nonperturbing approaches that utilize atomic radiation to probe low temperature discharges. We will measure spatially and temporally resolved densities of plasma species using laser-induced fluorescence. Optical emission measurements will also be correlated with mass-selected ion energy distributions of plasma constituents and Langmuir probe measurements of electron and ion densities. In addition, new techniques for the measurement of electron densities, such as an electron plasma wave detector, will be investigated. □

OPTICAL TECHNOLOGY DIVISION



Overleaf

Interference oscillations for correlated photons. Pairs of correlated photons at 702 nm, produced by optical parametric down-conversion in a 50 μm BBO crystal, travel multiple paths to coincidence detectors. The resulting interference envelope containing high frequency oscillations may be used to measure the polarization mode dispersion of intervening material.

TECHNICAL ACTIVITIES

OPTICAL TECHNOLOGY DIVISION

MISSION

The Optical Technology Division of the Physics Laboratory provides national measurement standards and support services to advance the use and application of optical technologies spanning the ultraviolet through microwave spectral regions for use in diverse industries and governmental and scientific enterprises. In addition, the Division has the institutional responsibility for maintaining two SI units: the temperature scale above 1234.96 K and the unit of luminous intensity, the candela. 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 basic, long term theoretical and experimental research in photophysical and photochemical properties of materials, in radiometric and spectroscopic techniques and instrumentation, and in application of optical technologies.

To accomplish these goals in a responsive manner, the Division works closely with industry and other government agencies in developing programs to meet specific optical measurement needs. The Division maintains a broad range of fundamental and applied research programs, calibration services, and Standard Reference Material (SRM) production to accommodate the needs of the optical technology 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 for Optical Radiation Measurements (CORM) and the International Commission on Illumination (CIE). CORM and CIE are technical organizations that include a strong industrial constituency. As a result, these organizations provide the Division valuable insight on identifying the emerging needs of American industry which must be met to support the growth of quality manufacturing efforts and the broad range of products that utilize optical technology. Meeting these needs assists American industry in maintaining a competitive posture in the world market.

ORGANIZATION

The Division employs approximately 50 scientists, engineers, and technicians, and maintains a balanced mix of research, development, and measurement support services. It is organized into five groups and operates under a project structure which promotes collaborations across group administrative 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 work jointly on various tasks, sharing resources to achieve common goals. A recent collaboration with Division 841 has led to the formation of projects that span divisional boundaries. The project structure is sufficiently flexible to allow for redirection of resources to accomplish newly identified program goals and has proven to be a useful management tool for assigning responsibility and tracking progress.

CURRENT DIRECTIONS

- **Cryogenic Radiometry.** The Division maintains an absolute High Accuracy Cryogenic Radiometer (HACR) with a combined relative standard uncertainty of 0.02% as the foundation for a radiometric measurement chain to maintain scales of spectral radiance and irradiance, photometry, and absolute detector responsivity. A second, high-sensitivity cryogenic radiometer serves as the 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 areas where high-sensitivity infrared sensors are used. A new cryogenic radiometer has been purchased for installation at the Synchrotron Ultraviolet Radiation Facility (SURF) for use on a monochromator system, in order to establish the SURF spectral radiance scale on an absolute detector footing. Improvement of these radiometers for sensitivity and versatility is being pursued. Development of new radiometers incorporating superconducting technology and high T_c materials is also an important component of the cryogenic radiometry program.

The cryogenic radiometers are used to calibrate transfer standard detectors which are used throughout the Division in radiometric applications. The Division is also developing a series of transfer standard detectors to enable the high-accuracy radiometric scales to be propagated to other laboratories. Transfer standards are also being developed at near-infrared and ultraviolet wavelengths. In addition, a Laser Comparator Facility will be brought into service to allow the calibration of working standards against the HACR-calibrated transfer standards.

■ **Synchrotron-Radiation-Based Radiometry.** NIST is developing SURF III (Synchrotron Ultraviolet Radiation Facility), an advanced radiometric light source of unprecedented accuracy and spectral range. When commissioned in 1998, the SURF III electron storage ring will be an extremely bright, absolutely predictable source of light spanning the electromagnetic spectrum from soft x-rays through far infrared. The radiation emitted by SURF III will be critical for such applications as: setting new standards for electromagnetic radiation power measurements; calibrating photodetectors and optical instrumentation for use in the semiconductor industry and in space research; verifying high-temperature radiation thermometry scales; and opening new research opportunities in longer wavelength regions (infrared and terahertz). The Optical Technology Division, Electron and Optical Physics Division, and Atomic Physics Division are collaborating to develop the new facility.

SURF has served for many years as the national standard for radiation power measurements in the far ultraviolet. The major facility upgrade to SURF III will substantially improve the accuracy and extend the spectral range of optical measurement and research available at NIST, primarily by improving the magnetic field uniformity of the storage ring by two orders of magnitude, thereby reducing the uncertainty in SURF III as a radiometric source. SURF III will be used for both source-based and detector-based radiometry. Source-based radiometry exploits the predictability of the power, spectral, and spatial distributions of radiation emitted by the electrons accelerated in the storage ring, based on fundamental physical principles. Detector-based radiometry will use SURF III as a bright light source, particularly in the ultraviolet and soft x-ray spectral regions, basing measurements on absolute detectors including a newly developed cryogenic electrical substitution radiometer optimized for short wavelengths.

■ **Temperature.** The Division has the institutional responsibility to maintain temperature scales above the freezing point of silver (1234.96 K) and radiation temperature scales at all temperatures. 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 blackbody sources are maintained for calibration purposes and span the temperature range from approximately 100 K to 3000 K. 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. Two NIST competence programs are underway in efforts to remove uncertainties from the International Temperature Scale and to improve heat flux measuring techniques. New methods of using synchrotron radiation and blackbodies to establish a new independent temperature scale are being undertaken in conjunction with the SURF III upgrade.

■ **Photometry and Colorimetry.** Photometry, the science of measuring light with the response function of an "average" human observer, is integral to the detector metrology program. The SI 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 candela, and provides an alternate method, other than conventional lamps, for transferring calibrations of this unit to customers. While the practice of lamp dissemination will be continued, depending upon lamp availability, the Division can offer photometric detector characterization to customers as a more direct and perhaps more stable calibration procedure. The Division has developed a total luminous flux scale based upon the new candela and hence directly upon the HACR. The Division is participating in a new NIST competence program to develop and improve the physical measurement basis for colorimetry and associated appearance quantities.

■ **Optical Properties of Materials.** Two absolute spectrophotometric instruments serve to maintain the scales of transmittance and reflectance. Additionally, the optical density scale will be maintained using the transmittance instrument. The reference transmittance and reflectance spectrophotometers both provide intrinsic uncertainties of a part per ten thousand in the 200 nm to 2500 nm wavelength range. In addition to a range of calibration services, the staff uses these instruments to prepare SRM materials for distribution to industrial and scientific customers.

For the spectral range from 2 μm to 25 μm a high-accuracy prism-grating monochromator for transmittance measurements has been built, and research is being pursued to characterize Fourier Transform Infrared (FTIR) instrumentation for quantitative spectrophotometry. Transmittance, specular reflectance, and diffuse reflectance measurements are being performed at close to 1% uncertainty using the FTIR instrumentation. Laser-based spectrophotometry is also being developed to corroborate and supplement these measurements, and cryogenic capabilities are being added to perform measurements for a wide range of sample temperatures.

The Division also maintains laser-based instruments for hemispherical reflectance, Bidirectional Scattering Distribution Function (BSDF), and Bidirectional Reflectance Distribution Function (BRDF) for high-accuracy, low-level transmitted and reflected scattering measurements. These instruments and related ones, as well as a planned infrared beam line and microscope at SURF, establish a capability to characterize optical properties of materials over a broad range of conditions. In addition, the Division is developing material-characterization methods using advanced optical tools such as Near-field Scanning Optical Microscopy (NSOM), nonlinear spectroscopy of interfaces, and femtosecond spectroscopy. A collaborative program among several divisions in the Physics Laboratory to develop of theoretical tools to predict the optical properties of materials helps meet the long-term goal of providing an optical properties data base for the Nation's advanced manufacturing efforts.

■ **Optical Scattering Metrology.** Mechanisms by which material properties and surface topography effect the distribution of light scattered from surfaces are studied with an aim toward developing standard measurement methods and standard artifacts for use in industry, and to provide a basis for interpreting scattering distributions so that industry can optimally use optical scatter methods. Applications include evaluation of highly polished optical surfaces, bulk optical materials, surface residues, and diffuse scattering materials. Optical scattering metrology is also used to assess uniformity of periodic structures, such as pits on compact discs, patterned photoresists, and deposited lines on semiconductors. Experiments and theoretical modeling are underway to use optical scatter to distinguish surface microroughness, particulate contamination, and subsurface defects on silicon wafers.

■ **Near-field Scanning Optical Microscopy (NSOM).** NSOM is being developed as a quantitative technique for noninvasive optical measurements. Its resolution is not limited by the wavelength of light, as in traditional diffraction-limited microscopies, but by the size of the sub-wavelength aperture or tip used as a probe. Well-characterized microscopes and small light sources are being constructed, and work on methods to determine the resolution of commercially available near-field microscopes is in progress. This requires fundamental understanding of contrast mechanisms and modeling the fields around small light sources as they interact with materials and surface features. The Division collaborates with other NIST programs applying near-field microscopy to problems in chemical, biological, optical, and semiconductor technology.

■ **Spectroscopy and Dynamics at Interfaces.** Femtosecond lasers are used to measure rates and mechanisms for technologically important interface processes, such as the coupling and relaxation of excited carriers, phonons, and surface electronic and vibrational states (particularly molecular states) at metal, semiconductor, and dielectric solid and liquid interfaces. The initial states are excited by an ultrashort laser pulse, and the subsequent evolution is measured with time-delayed probe laser pulses. Surface-sensitive probe techniques include infrared absorption and sum frequency generation (SFG). Nonlinear optical diagnostics such as SFG are uniquely sensitive to interface structure at the surfaces of materials, in thin-film systems, or buried in layered materials. Additional measurement applications include spectroscopic characterization of electronic structure at buried epitaxial interfaces, assessment of the structure and quality of thin films, and vibrationally resonant SFG of organic films such as self-assembled monolayers and molecules at liquid interfaces.

■ **Femtosecond Condensed-phase Transient Spectroscopy.** Ultrashort laser pulses are used to observe fast processes occurring in the condensed phase. Unique femtosecond infrared spectroscopic techniques have been developed to study highly excited vibrational states, vibrational energy transfer, photochemical reactions, and the dynamics of hydrogen bond formation and rupture. The measurements identify transient species and determine energy transfer rates which serve to improve models of condensed phase chemistry. Current collaborations with industry include measurements on catalytic systems and polymerization reactions.

■ **Laser Studies of Elementary Chemical Reactions.** Laser pulses are used to observe and manipulate fundamental molecular transformations, such as bond breaking and bond formation, in order to develop an atomic-level understanding of reactions important in combustion and propulsion chemistry, in the chemistry of the upper atmosphere, and in orbital environments. Current efforts emphasize elementary reactions of O-atoms with H_2, H_2O, HCN, and CH_4. The experiments use state-resolved nanosecond and time-resolved femtosecond spectroscopic techniques to produce data to test quantum chemical models of these benchmark systems.

■ **Environmental and Remote Sensing.** In response to the U.S. Global Change Research Program (USGCRP), NASA, NOAA, EPA, and other government agencies are supporting a wide range of space-based and terrestrial research programs to ascertain the effects of human activities on the biosphere. These programs envision long-term monitoring and survey activity which require consistent calibration of instruments from diverse parts of the world. NIST and NASA have established a jointly funded effort to provide a comprehensive calibration base for radiometric instruments that will involve reference to the cryogenic radiometers maintained in the Division. In addition to actual calibrations, NIST will engineer round-robin calibration efforts among the instrument manufacturers and provide cross calibration with other national laboratories involved in USGCRP activities. In particular, NIST expects to work closely with NASA on the Earth Observing System (EOS) platforms to insure calibration quality prior to launch and to assist in checking calibration accuracy after launch. NIST has established a solar UV monitoring station and will supply the underpinning of the calibration activities of the worldwide UV monitoring program envisioned by the USGCRP as a crucial aspect of determining the effects of stratospheric ozone depletion. The Division is also undertaking spectroscopic measurements of the absorption spectra of atmospheric molecules for the refinement of atmospheric transmission and radiative transfer models, necessary for remote sensing and global change efforts.

■ **Analytic Spectroscopy.** Optical technology is increasingly important for applications in chemical analysis and detection, including atmospheric remote sensing, emissions monitoring, catalysis, industrial process control, forensic science, medical diagnostics, chemical manufacturing, and materials development. The Division has a vertically integrated research and development effort to support this technology. The effort includes: (1) establishment and dissemination of spectroscopic data bases to facilitate choices of monitoring frequencies and inversion of measurements to extract concentrations; (2) development of quantum mechanical Hamiltonians which provide convenient and concise representations of spectroscopic data and their validation; (3) laboratory spectroscopic measurements to provide accurate frequency and intensity information for instrument calibration; (4) development of new optical chemical sensor technology in the microwave, infrared, and visible/UV spectral regions; (5) working with other government agencies to solve novel and important chemical analysis and detection problems; and (6) interacting with industry to transfer these technologies and learn about the needs for new optical chemical analysis technologies, standards, and data.

■ **Consultation and Calibration Services.** The Division staff provides SRMs 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, EPA, USDA, FAA, and DoD to develop calibration programs appropriate for their demanding missions. The Division has completed an ambitious program to implement ISO Guide 25 standards in all the calibration services during the past year and is developing a protocol for assessment of the quality program.

HIGHLIGHTS

■ **Optical Metrology for Photolithography.** Smaller, faster microelectronic devices can be made by using shorter wavelengths for photolithography, but creating the next generation of photolithographic tools operating at 193 nm poses unprecedented challenges for the purity and characterization of optical materials. The Division participates in an extensive collaborative effort, involving several NIST laboratories, the National Semiconductor Metrology Program, SEMATECH, materials suppliers, stepper manufacturers, and MIT Lincoln Laboratory to provide measurements and support for characterization of the optical properties of fused silica and calcium fluoride. The Division activity is focused in three areas:

- Critical dimensions at this shorter wavelength require smaller focus budgets and tighter control over the lens design, which are not tenable without accurate knowledge of the refractive index and the thermal coefficient of the refractive index of fused silica and calcium fluoride. We have developed a UV reflectometer capable of measuring the refractive index at 193 nm with an accuracy of 10^{-5}, which is sufficient to meet the industry's immediate need. For the longer term and for shorter wavelengths, we are developing interferometric methods capable of higher accuracy. (R. Gupta)
- Optical scatter at 193 nm from surfaces and from within lenses degrades photolithographic images, and complicates critical transmission and absorption measurements performed on the materials. We have performed total integrated scatter measurements that show that the intrinsic Rayleigh scatter coefficient in fused silica is on the order of 0.001 cm^{-1} at 193 nm, a value considered to be the maximum tolerable level for this application. The scatter in calcium fluoride, which is a candidate to replace fused silica as photolithography moves to shorter wavelengths, was substantially lower, as expected for a crystalline material. (C.C. Asmail and T.A. Germer)
- Accurate reflection, transmission, and absorption measurements are essential to optical design since absorption modifies the temperature-dependent refractive index. NIST has developed an instrument capable of making these measurements, and has assisted Lincoln Laboratory researchers in the characterization of their transmittance instrument. (D.J. Dummer)

■ **Intrinsically Absolute Metrology Using Correlated Photons.** The Division is investigating the application of correlated photon techniques to metrological problems. Using correlated photons, we have developed methods to measure absolute detector responsivity without externally calibrated standards. We have also developed methods to measure infrared source radiance in a direct intrinsically absolute manner. An additional technique that we are developing uses correlated photons to determine absolute polarization mode dispersion in optical materials. In this application, pairs of correlated photons propagate collinearly but with orthogonal polarizations. Since photons of a pair are created simultaneously, any shift in the timing between the two is indicative of polarization mode dispersion in intervening material. The accuracy with which the time shift is measured determines the accuracy of the polarization mode dispersion measurement. The potential accuracy of the method is better than 0.1 fs.

The correlated pairs of photons are produced by an optical parametric down-conversion source and detected via coincidence circuitry. An optical arrangement with multiple paths allows for coincidences via multiple indistinguishable paths, leading to quantum interference that is seen as a modulation of the coincidence rate. When the two coincidence paths differ by more than a coherence length of the photons, the paths become distinguishable, producing no interference, and the coincidence rates of the two paths are directly summed. When the paths differ by less than a coherence length, the two paths become indistinguishable, resulting in destructive interference that causes the coincidence rate to drop to near zero. This dip in the coincidence rate acts as a marker indicating a precise delay between the two photons. When a sample is added to the optical path, the change in the delay between the photons is encoded in the shift of this dip marker. A new optical arrangement with additional paths has the potential for higher ultimate measurement accuracy. That arrangement fills the previously described dip with high frequency oscillations (see figure on the cover of this section of the annual report), which may allow the shift of the dip to be determined with even higher resolution. (A.L. Migdall)

■ **Near-field scanning optical microscopy (NSOM): nanometer-scale characterization of optical fields.** NSOM has great potential for noninvasive optical characterization of nanostructured materials, but the application of NSOM as a metrological tool is limited because contrast and resolution are poorly understood or ill defined. To address this problem, we are studying the fundamental mechanisms in NSOM which generate contrast and determine resolution for different materials.

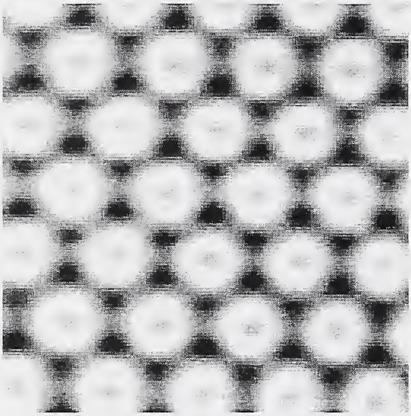


Figure 1. NSOM image of the optical fields produced by a nanochannel glass array. The image reveals local optical modes of the array which depend on crystal geometry and composition.

In collaboration with the University of Virginia and the Naval Research Laboratory, we have used NSOM to image a nanochannel glass array. The array is a two-dimensional "photonic crystal" composed of two glasses with slightly different indices of refraction. An array of glass cylinders (the channel glass) is embedded in another glass (the matrix glass). The channel glass elements are 745 nm in diameter, with a center-to-center separation of approximately 1100 nm. The NSOM image shown in Fig. 1 was recorded by illuminating the sample with a fiber-optic probe positioned about 10 nm above the surface. The probe is scanned across the sample surface and transmitted light is collected on the opposite side of the sample. This image is not strictly analogous to a microscope image, but contains additional information about the optical modes supported by the sample. The NSOM measurements, supported by quantitative models, show sensitivity to the local density of photon states in the array, which in turn depends on such properties as the index difference between the two glasses, the geometry of the crystal, and the composition of an interdiffusion layer between the two glasses. By varying the photon energy and the numerical aperture of the collection optic, contributions are observed from different optical modes of the array. The results demonstrate that NSOM can be used with detailed models to determine quantitatively nanometer-scale material properties, such as the spatial variation of the index of refraction, that cannot be measured by other techniques. (L.S. Goldner and E.L. Shirley with G.W. Bryant and P.S. Julienne of Division 842).

■ **Femtosecond Laser-Induced Desorption: Theory and Experiment.** Fundamental events which occur at surfaces and interfaces underlie many technologically important processes. For example, the exchange of energy among electrons in a metal and molecules at the metal's surface underlies catalysis, the non-thermal interaction of light at materials surfaces is responsible for photoetching in semiconductor device fabrication, and the scattering of carriers from interfaces influences the operation of devices. In collaboration with the Chemical Science and Technology Laboratory, we have used femtosecond lasers to measure characteristics of these interactions at surfaces. We studied the chemistry of carbon monoxide, CO, adsorbed on a copper single crystal, Cu(100), irradiated by ultrafast laser pulses. This system was chosen because unique state-of-the-art *ab initio* calculations for CO/Cu have just become available (from Lucent Technologies and University of California, Berkeley). Also, this system has been well characterized by many other experimental techniques that provide key information about bond energies, adsorbate vibrations, and substrate phonons, making it an ideal test of the theory.

Laser pulses of 160 fs duration impinged on a Cu surface, which was initially at a temperature $T_S = 100$ K and covered with an ordered half-monolayer (0.5 ML) of CO; each CO is bound directly on top of a Cu atom, C toward the surface. The laser pulse initially excites electrons in the bulk metal within 20 nm of the surface, creating hot electrons with a temperature $T_E = 3000$ K. Over the next several picoseconds, these hot electrons transfer energy to the metal bulk phonons, as well as to adsorbate vibrations such as the C-O stretch and the Cu-CO stretch (the molecule-metal bond). When the latter bond gains sufficient energy (about $T = 420$ K), the CO molecules desorb, and are detected in the gas phase by another laser, which determines the vibrational (T_V), rotational (T_R), and kinetic temperature (T_T) of the desorbed CO. Since the electrons and the various vibrations all have different temperatures for a brief time (2 ps), this type of experiment allows the relative importance of the different excitations to be assessed.

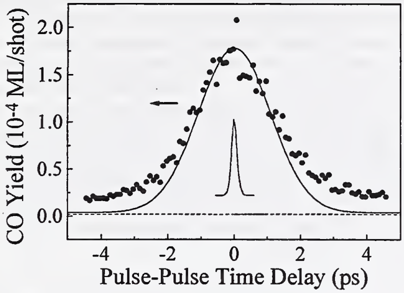


Figure 2. Yield (Y) of CO from a Cu(100) surface as a function of time delay (t_d) between two laser pulses of equal intensity (I) which cause CO desorption. Since Y scales as I^8, Y is strongly peaked at $t_d=0$. The 3 ps width is well fit by a model (solid line) developed at NIST. Inset shows autocorrelation of the 140 fs laser pulses.

The results for desorbed CO were $T_R = 225$ K, $T_V = 1330$ K, and $T_T = 215$ K. The desorption yield varied nonlinearly with laser fluence ($Y = F^8$). These data agreed well with the *ab initio* theory in which energy is exchanged between hot electrons and vibrations though electronic frictions. The results also agreed with an empirical model developed at NIST, in which readily available data (*i.e.*, desorption rate parameters and vibrational damping times measured under thermal low-temperature conditions) was used to predict the reactions of this system under the experimental conditions which were far from equilibrium. The agreement with both the theory and the model is very encouraging, providing insight and a method that can be used to predict results of other surface processes, whether or not induced by femtosecond lasers. Since the interaction of ultrashort laser pulses with materials is becoming common in communications, in measurement technologies, and in other fields, validation of such models is increasingly important. These results have been accepted for publication in Physical Review Letters. (J.C. Stephenson with Division 837 researchers L.M. Struck, L.J. Richter, S.A. Buntin, and R.R. Cavanagh)

■ **Haze on Silicon Wafers.** Measurements of optical scatter are often employed in production line diagnostics for surface roughness of silicon wafers. However, the geometry of the optical scatter instrumentation lacks standardization, making if difficult to compare values obtained by instruments made by different manufacturers. The Bidirectional Reflectance Distribution Function (BRDF), on the other hand, is a well-defined quantity, and under conditions usually met with bare silicon wafers, can be related to the power spectral density (PSD) of the surface roughness. We have developed an approach for characterizing low-level optical scatter instrumentation using a spatial frequency response function. The function gives the sensitivity of an instrument with a specified geometry to microroughness on different length scales, allowing the haze signal to be treated as an integration of the PSD with the response function. Algorithms were developed for calculating this response function for different geometries, and a computer program will be made available which will allow instrument manufacturers to calculate the response function for each of their products. This methodology is being incorporated into ASTM documents describing the standard practice for calibration of scanning surface inspection systems. (C.C. Asmail and T.A. Germer)

■ **Large Aperture Blackbody Calibrations at the NIST Low Background Infrared Calibration Facility (LBIR).** An upgrade to the LBIR facility has been completed with the addition of an ante-chamber to the broadband calibration chamber. There has been a demand from infrared space-based missions to calibrate higher temperature and larger aperture blackbodies than the facility was able to accommodate in its original design. This new addition was developed in collaboration with Los Alamos National Laboratory for the calibration of two blackbodies which have 10 cm and 18 cm diameter apertures and operating temperatures from 250 K to 350 K. These blackbodies will be used as sources in a new satellite sensor calibration facility under development at Los Alamos. At NIST, they will be operated in the evacuated ante-chamber with shrouds cooled by liquid nitrogen. The ante-chamber is attached at the source end of the LBIR chamber with a precision aperture. The typical flux levels at the radiometer aperture, which is located one meter away in the LBIR chamber, will be in the range of 2 μW to 10 μW. A two-axis translation stage is also available to allow spatial measurements of the radiance temperature. This new capability removes many of the constraints on customer blackbodies that were to be operated in the original cryogenic chamber, such as size and total power dissipation. (S. Lorentz)

■ **Medium Background Infrared Facility.** Infrared radiometry has an important role in space-based civilian, defense, and industrial applications. The growing realization among users of infrared radiometers of the critical role for calibration and characterization of these devices has led to the development of a new Medium Background Infared (MBIR) Facility in the Division. This facility will be used to maintain an infrared scale for specialized applications that involve radiometric instruments that need to operate in a vacuum environment surrounded by a light-tight shroud cooled to as low as 80 K with liquid nitrogen. NIST has had facilities for infrared radiometric measurements in ambient environments and at the 20 K Low-Background Infrared (LBIR) Facility, but had lacked a facility for the increasingly important medium (80 K) background applications. In particular, the capability will be established for measurements on large-area, vacuum-operational, blackbody sources operated from 200 K to about 400 K, which are traceable to NIST via infrared radiometry through the radiance temperature of the source. An example of the type of scientific activity that the MBIR facility will support is the use of earth-orbiting satellites for the determination of temperature of the earth's surface and atmosphere by radiance measurements. These measurements are the basis for the study of global warming. To establish radiometric traceability of satellite instruments to NIST, the Division is developing a liquid-nitrogen cooled, portable infrared radiometer. It will be used to intercompare large-area blackbody sources at contractors' facilities in NASA's Mission to Planet Earth Project. The MBIR facility will be used to characterize and maintain the NIST calibration of this portable radiometer. (J. Rice)

■ **Modeling Optical Properties of Materials.** The Division is developing a capacity to model and predict optical properties of materials, using state-of-the-art first-principles methods, as part of its long-term strategy to facilitate improved optical metrology. Optical properties such as a material's refractive index and absorption spectra depend on the description of electron-electron interactions at a level of detail which challenges current algorithms, models, and computers. Present activities are focused on the description of such interactions and their effects on x-ray absorption spectra extremely close to atomic x-ray edges (within ~10 eV of an edge). In such energy regions, standard methods used to describe absorption at higher energies are not suitable because of their incomplete description of electron interactions. Planned activities for the coming year include an assessment of techniques in a wider range of materials than those studied thus far (e.g., hexagonal boron nitride, Fig. 3), and adaptations of the techniques to the more difficult problem of visible and soft ultraviolet absorption spectra of semiconductors and insulators, as well as seeking improvements in the first-principles modeling of infrared absorption because of atomic vibrations. (E.L. Shirley and R.U. Datla)

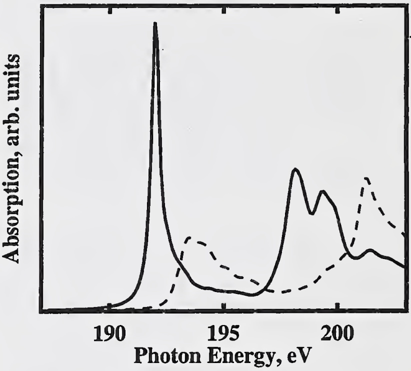


Figure 3. First-principles x-ray absorption of hexagonal boron nitride, including electron interactions (solid line), and omitting such interactions (dashed line). Including electron interactions dramatically improves agreement with experiment.

■ **High-Contrast Broadband Infrared Polarizer.** The Optical Technology Division has constructed and tested a linear polarizer for use with a broad range of visible and infrared radiation. The device works on Brewster angle reflections from four germanium plates arranged in a chevron geometry. Tests with 0.633 μm and 3.39 μm wavelength laser radiation have shown extinction ratios (defined as the ratio of the transmittances of p and s polarized light) of 4×10^{-6} and 3×10^{-7}, respectively. The extinction ratio is expected to be less than 10^{-6} for wavelengths up to at least 25 μm. Development of polarization metrology in the infrared at NIST is being driven by the increasing importance of polarized light measurement capability in such diverse fields as optical communication, pharmacology, and infrared imaging. These applications depend on the quality and calibration of polarization components. The high-quality linear polarizer that has been developed is expected to find use directly in specialized applications, and as a calibration standard. (D. Dummer, S. Kaplan, A. Pine, and L. Hanssen)

■ **New THz Source Developed for Spectroscopic Studies.** A new scheme involving generation of coherent, tunable, far-infrared radiation by mixing two visible laser beams in an ultra-high-speed photoconductor has resulted in the development of a new THz spectrometer. This work has been carried out in collaboration with MIT Lincoln Laboratory. The ultrafast photomixers were fabricated at Lincoln Laboratory using an epitaxial layer of low-temperature-growth (LTG) GaAs on a semi-insulating GaAs substrate. The LTG GaAs material has subpicosecond recombination lifetimes, enabling a frequency response to several THz. Microscopic interdigital electrodes driving a broadband self-complementary spiral antenna are deposited on the material using lithographic techniques. The THz radiation is coupled out of the GaAs photomixer into free-space using a high-index Si aplanatic lens and is detected using a conventional liquid-He-temperature bolometer. The new spectrometer has been used to record the rotational spectrum of SO_2 in the 0.1 to 1.2 THz region. The new spectrometer has also been used to obtain pressure-broadening parameters for these SO_2 transitions. (A.S. Pine and R.D. Suenram)

■ **Calibration of Night-Vision Equipment.** The available radiometric calibration methods for night-vision transfer-standard detectors and goggles have been limited to an uncertainty of approximately 10%, which is inadequate for most purposes. This limited accuracy exists because the calibration chains are long and the precision of the calibrating equipment is poor. In order to improve accuracies and calibration techniques in DOD laboratories and in the night-vision industry, standard detectors must be calibrated for both radiance and irradiance responsivities traceable to high-accuracy standard detectors. NIST has developed a facility to calibrate night-vision transfer-standard detectors in spectral radiance and irradiance response modes against NIST detector-based radiometric scales. A large output area, monochromatic sphere source has been developed for the visible and near infrared wavelength ranges. Standard-quality silicon irradiance and radiance detectors have been designed and fabricated. Calibration equipment has been designed and realized with precision geometry in order to make an accurate flux-measurement transfer between the different radiometric calibration modes. A detector-based spectral radiance and irradiance response calibration system is now available at NIST for accurate and uniform calibration of night-vision transfer-standard radiometers. (G. Eppeldauer)

■ **New Photometry Capabilities.** The Division is responsible for the realization of the candela, one of the SI base units, and other photometric units for luminous flux, illuminance, luminance, and color temperature. The NIST photometric units are based on standard photometers which are traceable to the Division's High Accuracy Cryogenic Radiometer (HACR), which has a combined relative standard uncertainty of 0.02%. Using detector-based methods to realize the photometric scales at NIST has reduced uncertainties of photometric calibrations and has resulted in the availability of additional photometric calibration services at NIST. These improved services impact on a variety of industries. Examples of products that rely on photometric standards are lighting, display, optical instrumentation, and illuminated safety devices for the automotive and aircraft industries.

Recently, significant advances have been made in the Division's photometry capabilities. In 1995, a new luminous flux unit was realized using an innovative integrating sphere method. Using this method, the NIST lumen is now also traceable to the HACR. This new unit has been disseminated to customers since January 1996. Standard lamps for luminous intensity and color temperature were made available in 1994 and calibration of linear fluorescent lamps for luminous flux was added in 1995. A high illuminance source was developed in 1996, making possible illuminance calibration up to 100,000 lux. In addition to these recent developments, the Division accepts various artifacts for calibration, such as illuminance meters, luminance meters, standard photometers, sphere sources, opal glass, as well as various types of transfer standard lamps for luminous intensity and luminous flux.

A new publication, Photometric Calibrations (SP 250-37), describes these expanded capabilities. It replaces the previous SP 250-15 (1987) and provides extensive information on the realization of the NIST detector-based photometric units and the new calibration procedures for luminous intensity, illuminance, luminance, luminous flux, and color temperature.

Work is in progress to establish illuminance measurement standards for flashing lights. Accuracy of the measurement of flashing anti-collision lights is critical to the aircraft industry. The Division plans to offer a calibration service for flashing-light meters in late 1997.

Another new activity involves the measurement of color. Colorimeters are often used during the manufacture of commercial display units (television and computer monitors) to calibrate color. However, it is often difficult and expensive to calibrate these instruments correctly. It is especially important in the computer industry to accurately calibrate colorimeters, since this industry puts a premium on correctly calibrating the appearance of computer displays. To answer these needs, the Division is establishing a project for colorimetry of displays and imaging devices with the goal of ultimately offering calibration services in this area. Research will be focused on the characterization of various color displays including flat panel displays and color reproduction through color imaging devices. (Y. Ohno)

■ **Calibration Quality Program.** In response to NIST customers' requests and to help lead the nation into the future of laboratory accreditation, an effort has been established in the Optical Technology Division to document its quality system for the calibration services it offers. The calibration services participating in the effort are: Radiance Temperature Measurements, Spectroradiometric Source Measurements, Optical Properties of Materials Measurements, Photometric Measurements, and Spectroradiometric Detector Measurements. The quality system is based on ANSI Z540-1-1994, the American National Standard for Calibration and Testing Laboratories. Several key sections of the standard have been implemented. Quality manuals have been written for each calibration service offered by the Division. Computer software and calibration methods have been uniformly documented in the quality system. Uniform test-report formats are issued by the Division's calibration laboratories. In addition, the Division has adopted a standard procedure for handling customer complaints. An internal audit was completed in FY 95. In FY 96 the Division's quality manager and the deputy quality manager completed both internal auditor training from NVLAP and lead assessor training approved by Registrar's Accreditation Board and the International Register of Certified Auditors. Compliance with the ISO quality standard and the effort to document the quality system will benefit the services offered by the Division. (T. Larason and S. Bruce)

FUTURE DIRECTIONS

■ **Synchrotron Efforts.** A beamline for infrared and far-infrared spectroscopic applications is being developed for the SURF III synchrotron storage ring. The 100 to 1000 times higher brightness of the synchrotron source offers many advantages over conventional high-temperature black-body infrared sources for applications in microscopy, polarimetry, and high-resolution interferometry. An infrared microscope and Fourier transform spectrometer will be attached to this beamline for materials characterization and analysis, with applications in such areas as polymer science, forensics, and high-pressure chemistry. Future incorporation of infrared array-detectors will provide a unique infrared microscopy facility for large-scale chemical mapping of materials at extremely high sensitivity. The polarization characteristics of the synchrotron source will be explored to develop polarimetry and ellipsometry for measurement of optical properties of materials in the infrared. As a companion effort to the infrared beam line development, efforts are also underway to explore the utility of SURF III as a far-infrared/submillimeter radiation source. At these longer wavelengths, where the wavelength of the radiation approaches the electron bunch size, coherence effects are possible.

■ **Construction of a Next-Generation High-Resolution Laser/Molecular Beam Spectrometer.** A new visible/ultraviolet (UV) high-resolution laser spectrometer is being developed to elucidate the structure and dynamics of molecules and molecular complexes at full rotational resolution in electronically excited states and at chemically-relevant energies. The instrument will permit structural and electronic information to be obtained from the rotationally-resolved spectra of large, organic molecular species that are important in studies of the design of pharmaceuticals, acid-base reactions, proton transfer, hydrogen bonding, and polymeric materials with novel electronic properties. The instrument itself will use a tunable narrow-band (linewidth <1 MHz) frequency-doubled cw dye laser. The sub-Doppler rotational structure will be resolved with the use of a novel spatially-selective light collection assembly coupled to a CCD detector array.

■ **New Optical Sensors for Flow Diagnostics and Imaging.** Optical diagnostics offer an accurate, sensitive, real-time, non-intrusive method for monitoring flowing chemical systems found in industrial processes, wind tunnels, rocket exhausts, gas-turbines, and factory emissions. The initial development effort, based on mid-infrared lead-salt diode lasers, offers high sensitivity since fundamental vibrational modes of the molecules are probed, but suffers from expense, complexity, and poor spatial mapping characteristics. Future efforts will exploit advances in optical communication technology by using low-cost, compact, near-infrared diode lasers and fiber optics propagation. Efforts are also being undertaken to use Coherent Anti-Stokes Raman Spectroscopy (CARS) for optical diagnostics.

■ **Applications of THz Optical Technology.** Recent technological advances in solid-state devices, lasers, and instrumentation have enabled development of new broadly-tunable spectral sources in the THz region for new applications. One application will employ Russian-made, backward-wave-oscillators (BWOs) (a technology only recently available to Western researchers) coupled with a flow-through acoustic absorption cell for monitoring trace amounts of gases such as CO, H_2O, HCl, SO_2, H_2S, H_2CO, and NH_3 in industrial process streams. The THz region can be electronically scanned in seconds, permitting real-time acquisition of spectral data for chemical process control.

Developments in ultrafast laser technology present opportunities for generation and detection of pulsed terahertz radiation for use in diverse applications, including imaging, ranging, trace species detection, time-resolved spectroscopy of biological and chemical systems, and characterization of optoelectronic and superconductor materials and devices. We plan to develop femtosecond THz capabilities to measure indices of refraction, carrier dynamics, and other transport properties of photonic materials and structures, and to characterize protein-surface interactions and metalloprotein electron transfer rates in biocatalytic reactions.

■ **Improved Radiometry for Environmental Monitoring.** Environmental and health concerns about the penetration of UV radiation into the biosphere due to ozone depletion underscore 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-based and earth-based sensor systems. NIST is in a unique position to offer long-term measurement support to USDA, NASA, NOAA, EPA, DOE, universities, and industrial laboratories studying the long-term consequences of increased solar UV on the biosphere. The space-based sensor systems being developed for deployment in the NASA EOS program have stringent accuracy requirements for radiometric calibration in the wavelength region from 200 nm extending into the far infrared. The requirements pose a new challenge for radiometry at NIST and the measurement infrastructure NIST supports.

■ **Improved Radiometric Standards.** U.S. industry has expressed the need for improved radiometric standards for a variety of technical, competitive, and production-quality reasons. These needs were documented in the 5th CORM Report and reaffirmed in the 6th CORM Report, released in December 1995. Issues raised in the reports serve as impetus for many of the Division's current and planned programs. A challenge for the Division remains to continually implement new methodology and instrumentation to meet the needs of our customers for the improvement and availability of a wide range of services, SRMs, and calibrations.

■ **Increased Range of Absolute Detectors.** NIST Technical Note 1421, "A National Measurement System for Radiometry, Photometry, and Pyrometry Based upon Absolute Detectors," outlines a strategy for the Division's customers to shift to a detector methodology for many of their radiometric and photometric needs. Over the last several decades, absolute detectors have been developed to serve as a fundamental radiometric tool to relate, with high-accuracy, optical power to the SI units. A challenge is to develop this capability for all wavelengths of interest, from the ultraviolet through the far-infrared, and at the various power levels needed by calibration customers. In terms of optical power, measurement demands can span more than 12 decades of intensity, with a variety of detectors and environments. In many calibration activities, detector-based radiometry can replace traditional source-based techniques and achieve significantly improved accuracy and stability. The Division must provide the technical base for this conversion and the leadership and guidance to achieve operational improvement in the customer's application.

■ **Imaging Radiometry.** Electronic rendition and storage of images offer 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 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. In an application of imaging radiometry, the Division has embarked upon a project to use imaging techniques to perform temperature measurements in the rapid thermal processing (RTP) environment used in the semiconductor industry.

■ **Laser-Based Detector Characterization Facility from the UV to the IR.** The accuracy of spectral radiometric measurements is often limited by the low spectral power density of traditional lamp/monochromator systems. Detector spectral radiance and irradiance response calibrations are best performed using intense, large-area, tunable, narrow-band, Lambertian sources, which are difficult to achieve with current methods. Another application requiring these source properties is the accurate measurement of the out-of-band rejection of narrow-band filters used in filter radiometers. In answer to these needs, a plan has been formulated to couple pulsed lasers and integrating spheres to produce intense, large-area, uniform radiation sources.

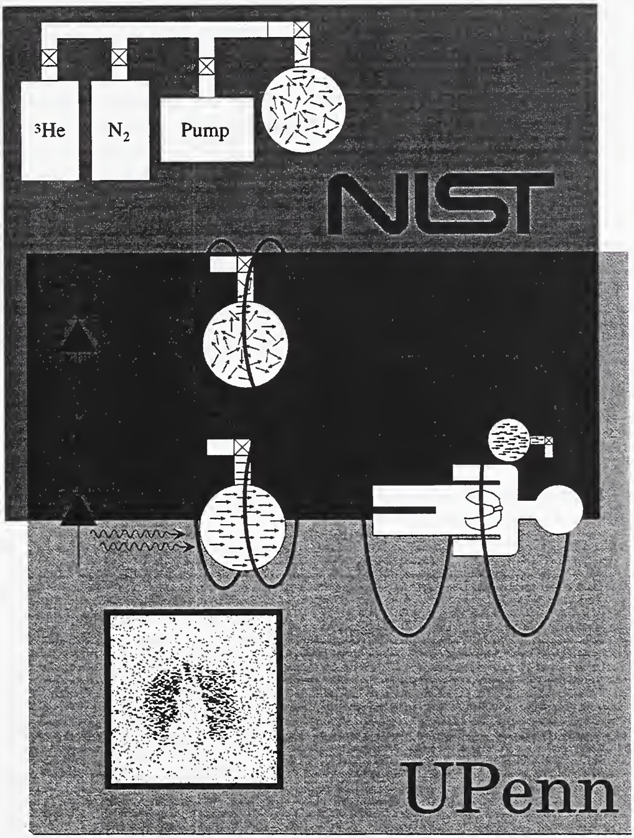
■ **Spectroscopy and Imaging of Biological Interfaces.** Optical measurements of interface structures and dynamics present opportunities for noninvasive characterization of biological films and living cells, and for biomedical imaging. NSOM is being developed to image biomimetic and *in vitro* biological membranes in order to characterize individual and clustered proteins and phase domains in these films. Sum frequency generation (SFG) will be employed to measure orientation and secondary structure of proteins in biomimetic membranes.

■ **Photophysics of Optoelectronic Molecules and Systems.** Intramolecular and interfacial dynamics are critical for the performance of optoelectronic molecules and molecule-based optoelectronic structures. Ultrafast time-resolved infrared spectroscopy will be used to measure rates of electron injection from optically excited photosensitizers to nanostructured semiconductor substrates. The aim is to develop the optical rate measurements as a guide to making modifications to the sensitizer.

■ **Magneto-Raman Scattering User Facility.** A program of experimental research in Raman spectroscopy of solid-state materials has been started in order to provide critical data to support electronic and optoelectronic technology. Equipment includes a DILOR triple-grating spectrometer equipped with a liquid-nitrogen-cooled CCD camera, an argon ion laser, and a superconducting solenoid magnet in a liquid-helium-cooled cryostat. Magneto-Raman spectroscopy of high-temperature superconducting materials is being investigated in collaboration with the Institute for High-Temperature Superconductivity of the University of Maryland. Collaborations for using this facility are being developed with industry, as well as with other NIST research groups.

■ **Direct Emissivity Measurements with LBIR.** The capability of making direct emissivity measurements of low-emissivity opaque and visually transparent materials has been developed using radiometric power measurements with the Absolute Cryogenic Radiometer in the LBIR chamber. This method complements emissivity measurements made using laser and FT spectrophotometric methods where the emissivity is calculated from reflectance and transmittance measurements. Characterization of materials having spectral emissive powers as low as 10^{-5} W/(cm^2·μm·sr) is possible using narrow bandpass filters over the range from 3 μm to 5 μm. In the future an infrared monochromator or additional filters will be used to cover the range of 2 μm to 30 μm. □

IONIZING RADIATION DIVISION



Overleaf

NIST/University of Pennsylvania collaboration on medical imaging. NIST has developed nuclear spin polarized helium-3 which has unique applications for lung imaging by Magnetic Resonance Imaging (MRI). A cell containing the nobel gas helium-3 is prepared at NIST and transported to the University of Pennsylvania Hospital in Philadelphia. A spin-exchange technique is then used to polarize the helium-3 nuclei. A normal human volunteer inhales a volume of the gas and a conventional MRI device is used to obtain an image of the lung cavity.

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 improved methods for radiation measurement, dosimetry, and 2- and 3-dimensional mapping of radiation dose distributions;
- develops improved primary radiation standards, and produces highly accurate standard reference data for ionizing radiation and radioactive materials;
- provides standard reference materials, calibrations, and measurement quality assurance services to users such as hospitals, industry, States and other Federal agencies;
- develops measurement methods and technology for use by the radiation processing industry, health care industry, nuclear electric power industry, environmental technology, and radiation-using industrial applications; 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 industrial companies, professional and governmental organizations and interested individuals from the radiation-user community repersented by 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 measurement services. The group structure consists of three technical groups: Radiation Interactions and Dosimetry, Neutron Interactions and Dosimetry, and Radioactivity.

CURRENT DIRECTIONS

- **Intravascular Brachytherapy Dosimetry.** A potential new application of interstitial brachytherapy, the prevention of restenosis following angioplasty, could result in an enormous increase in the use of beta-emitting sources for radiation therapy. Working with suppliers and the medical community, NIST is developing dosimetric measurement techniques, suitable for these short-range radiations, to provide calibrations to satisfy regulatory requirements and the needs of therapy planning. Current efforts include the accurate measurement of enclosed activity in candidate sources, and the correlation of this activity with the distribution of absorbed dose external to the source by means of state-of-the-art radiation transport calculations, thereby combining our strengths in radioactivity measurement, in experimental dosimetry and in radiation transport theory.

■ **Absorbed Dose Standards and Calibrations.** NIST has been preeminent in the direct realization of the absorbed dose in water, the quantity of interest for ionizing radiation, particularly in radiation therapy. Working with the medical physics community, we are implementing the direct transfer of the absorbed-dose-in-water calorimetric standard for ^{60}Co gamma rays through new calibrations of ionization chambers. The calibrations will be further disseminated by the secondary calibration network accredited by the American Association of Physicists in Medicine (AAPM), and will support the new AAPM protocol for dosimetry based on absorbed dose calibrations.

■ **Iodine-125 Brachytherapy Source Standards and Calibrations.** The recently developed Wide-Angle-Free-Air Chamber (WAFAC) will be the basis of a new standard for the dosimetry of brachytherapy seeds containing low-energy photon-emitters such as ^{125}I and ^{103}Pd. To support the consensus on providing the measurement that is more useful in therapy applications, the new standard and calibrations will discount the contribution to air kerma by characteristic x-rays produced in the titanium encapsulation. NIST is working closely with the medical physics community and manufacturers to introduce the new standard so as to maintain complete continuity in therapy dosimetry planning.

■ **Medical-Industrial Radiation Facility.** The 7 to 32 MeV electron linear accelerator facility has grown to be a significant user facility. The medical beam from the scanner/collimator head, which provides also for 25 MV photons, has been characterized and used for scattered radiation studies. Good progress is being made on the high-emittance port, configured for studies in the use of channeling radiation as a source of quasi-monoenergetic photons for digital-subtraction angiography. The high-intensity port is being used for applications ranging from radioisotope production to wastewater treatment to epoxy curing.

■ **Neutron Interferometry.** The Neutron Interferometer and Optics Facility is now in full operation as a national user facility with a busy schedule of experiments. Large new interferometer crystals of NIST design can operate over a wavelength range of roughly 0.2 nm to 0.45 nm, with fringe visibility as high as 88% at the shorter wavelengths. Experiments include applications for materials science as well as fundamental physics measurements.

■ **Neutron Fields for Materials Dosimetry and Personnel Dosimetry.** A diverse array of well-characterized and documented neutron fields is maintained for calibrations and for development of methods for materials dosimetry and personnel dosimetry. A new generation of staff has taken over these activities with continuing guidance from emeritus staff members, who are serving on contract or as guest researchers.

■ **Symmetries of the Weak Nuclear Force.** The end station on cold neutron guide NG-6 is also operated as a national user facility for investigation of the symmetries and parameters of the nuclear weak interaction. Two very different neutron lifetime experiments, a search for time-reversal asymmetry in neutron beta decay, and measurement of parity non-conserving spin rotation are competing for beam time.

■ **Laser Polarization of Neutrons.** Further progress in development of neutron spin filters by laser polarization of ^{3}He has included commissioning of our own cell-filling system, tests of a polarized cell on a neutron beam, and progress on development of a compact, low-cost compressor for ^{3}He which is polarized by the metastable optical pumping method at low pressures. In addition, collaboration with the University of Pennsylvania Medical School has produced an initial image of the human lung based on polarized ^{3}He magnetic resonance imaging.

■ **Neutron Cross Section Data.** This work focuses primarily on evaluation of standard cross section data and guidance of international data efforts. Experimental work is also in progress through collaborations at Ohio University, Los Alamos National Laboratory, and the Institute for Reference Materials and Measurements (Geel, Belgium).

■ **Standards, Calibrations and Instrumentation for Environmental Monitoring.** The measurement of environmental surface contamination, particularly around nuclear sites and in environmental remediation has posed an important and difficult problem. This program addresses the metrological needs in this area. Two systems that are under study and evaluation are (i) imaging plate technology and (ii) glow-discharge resonance ionization mass spectrometry.

■ **Radionuclide Standards for Nuclear Medicine.** NIST, in collaboration with the Nuclear Energy Institute (NEI), is targeting three nuclides for standard development/calibration this year. Of these, ^{62}Cu, a potential positron emission tomography (PET) agent for cardiac perfusion studies, is expected to be completed by the middle of this fiscal year.

■ **Radionuclide Metrology Development.** A pulse recording technique will be developed which permits a given data set to be analyzed *ex post facto*. Intercomparisons of the various types of analytical reductions on the same sets of data will be possible and indeed become routine, which will lead to reduced systematic uncertainties and very much faster measurements. Measurements of very short-lived radionuclides will become significantly easier.

There is also a need to compare liquid scintillation counting results for low energy γ-ray and β-particle emitting radionuclides with calibration values from other methods such as coincidence counting. Liquid scintillation has, in recent years, become the most used calibration method, combining speed, simplicity and high efficiency. It, however, must be demonstrated to give results equivalent to primary methods for low energy x-ray emitters such as ^{55}Fe and β emitters such as ^{63}N.

■ **Environmental Management and Nuclear Site Remediation.** A fast, inexpensive method for atom counting based on Resonance Ionization Mass Spectrometry will continue to be developed. Although much progress in this program has been made, the sensitivity must be improved by increasing the duty cycle.

The Nuclear Regulatory Commission is moving toward increasing sensitivity requirements for *in situ* measurements of radioactivity by a factor of 10 from that which can be attained by the present Ge-based systems. CdTe, HgI_2, and other room temperature, high Z detectors will be investigated and their characteristics developed to attain this goal.

HIGHLIGHTS

■ **Photon and Charged-Particle Data Center.** The Data Center compiles, evaluates, and disseminates data on the interaction of ionizing radiation with matter. The data on photons and charged particles, with energies above about 1 keV, include fundamental information on interaction cross sections as well as transport data pertaining to the penetration of radiation through bulk material. Databases are developed and maintained on attenuation coefficients for x-rays and gamma rays, including cross sections for Compton and Rayleigh scattering, atomic photoeffect, and electron-positron pair production, as well as on energy-transfer, energy-absorption and related coefficients relevant to radiation dosimetry. Work on charged-particle cross sections and of radiation transport data has entailed significant effort on the evaluation of the stopping powers and ranges of electrons, positrons, protons, and alpha particles, the elastic scattering of electrons and positrons, and the cross section for the production of bremsstrahlung by electrons. The quality of the work of the Data Center is reflected in the many requests for our data from other laboratories and in the use of our data in engineering and scientific compendia, books and review articles, and in the reports and protocols of national and international standards organizations. The compilations of the Data Center rely heavily on the synthesis of available theory to extend the data and provide for comprehensive coverage over broad ranges of energy and materials. Thus we have long been involved in complex computational analyses and in the development of highly sophisticated transport-theoretic methods. Our Monte Carlo transport calculations also are incorporated into some of the most widely used general-purpose radiation transport codes. (S.M. Seltzer, J.H Hubbell, and M.J. Berger)

■ **Beta-Ray and Hot-Particle Dosimetry Calculations.** Highly refined theoretical methods have been applied to beta-particle radiation protection practice. Participating in the work of an ICRU/ICRP Joint Task Group in updating fluence-to-dose conversion factors used in radiation protection we have made extensive electron Monte Carlo transport calculations of the depth-dose distribution of electrons incident on phantoms of water, PMMA, and tissue. These data, along with extensive tables of basic electron penetration data, a review of the physics of electron interaction and transport through matter, and a review of beta-ray transport calculations have been incorporated into ICRU Report 56, *Dosimetry of External Beta Rays for Radiation Protection*. Work with the NCRP Scientific Subcommittee on hot-particle dosimetry for radiation protection has involved extensive Monte Carlo calculations of the dose distributions from beta and gamma rays emitted by hot particles, which has led to the development of new point-kernel-based calculations for a variety of shapes and arbitrary sizes of beta- and gamma-ray sources containing virtually any radionuclide. These new calculations are being used for estimates of the dose distribution from a number of proposed brachytherapy sources. (S.M. Seltzer)

■ **Space-Shielding Radiation Dose Calculations.** With support from NASA's Life Sciences Biomedical Research Program, a computerized database and code package was 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. The database is based on 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 were evaluated in a straight-ahead approximation; a partial study of the effects of nonelastic nuclear interactions of the protons with aluminum nuclei and the transport of nuclear secondaries was included. The user code performs 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 various compositions. Numerous copies of this software have been distributed to the international space-radiation-effects community, and a collaboration is underway to incorporate this new work into an existing commercial package for estimating space radiation effects in any earth orbit. (S.M. Seltzer)

■ **Waste Treatment by Electron Beam.** We have been investigating applications of radiation (gamma and electron beam) technology for the reduction and elimination of hazardous waste materials generated in industry ("chemically hazardous" waste such as polychlorinated biphenyls). We are performing mass spectral analyses of PCB-contaminated water models. Samples are analyzed before and after irradiation with electrons and gamma radiation to determine the amount of toxins destroyed, yields and structures of products formed, and potentially toxic by-products induced by this emerging technological application. (L.R. Karam, and W.L. McLaughlin [with B. Wise and M. Al-Sheikhly, University of Maryland])

■ **Alanine-EPR Film Dosimeter.** Prototypes of a new polymer-based film dosimeter containing alanine have been manufactured and tested. This development program, under a CRADA with the W.R. Grace Co., is testing a range of polymer/alanine ratios for the film dosimeter. These tests were followed by comparative measurements on films of the same polymer/alanine ratio manufactured by different methods. The selected film formulation was mass produced and is undergoing extensive tests of its radiation response characteristics under a variety of conditions for gamma-rays and electron beams of different energies. Because films are easier to handle than pellets (presently the most common alanine dosimeter shape), it is hoped that the successful use of the thin (50 μm) film version for electron beams will lead to the development of a more robust film which would be easily adapted to high-dose gamma-ray processing applications. (M.F. Desrosiers)

■ **Radiation Sources.** The electron accelerators continue to be used for a large variety of radiation interaction studies. The principal sources currently being employed are the 4 MeV electron Van de Graaff and the 32 MeV Medical Industrial Radiation Facility (MIRF). The activities carried out on these sources will be specified in greater detail in other areas of this report but will be mentioned here. The Van de Graaff has been used to check the radiation response of new and existing types of diodes and solar cells. These include silicon on silicon, gallium arsenide on silicon and gallium arsenide, and indium phosphide on germanium and indium phosphide types. Additionally, this source has been used to investigate the shielding properties of various composites at electron energies between 1 and 2 MeV. The MIRF has been used for a large variety of programs including: production of radioactive isotopes of carbon, chlorine, fluorine, iodine and molybdenum; precipitation of heavy metals (lead and cadmium) from solution; degradation of polychlorinated biphenyls (PCBs); investigation of remote laser telemetering dosimetry; radiation curing of epoxies; production of radioactive fullerenes; investigation of radiochromic dye-gels; and the investigation of scatter from medical treatment beams. In addition to these ongoing programs, the beam line for the production of monoenergetic photon beams from the interaction of electrons in single crystals is nearing completion. (C.E. Dick and M.R. McClelland)

■ **International Comparison of X-ray and Gamma-ray Standards.** NIST has recently completed a number of comparisons of gamma-ray primary standards with those of other national and international standards laboratories. Cobalt-60 air-kerma standards were compared with the Ente Per Le Nuove Tecnologie, L'Energia E L'Ambiente (ENEA) in Rome, Italy; agreement was within 0.1%. A similar comparison was done for ^{60}Co with the Bureau International des Poids et Mesures (BIPM) in Paris, France, using the same transfer standards as was used with the ENEA. The agreement between the NIST and the BIPM standards is within 0.2%. These two comparisons provide NIST with additional corroboration of standards used for radiation therapy. In addition, a comparison of air-kerma standards for ^{137}Cs gamma-rays has been carried out among six laboratories: the Bundesamt für Eich- und Vermessungswesen (BEV), Vienna, Austria; the BIPM; the Laboratoire Primaire des Rayonnements Ionisants (LPRI), Gif-sur-Yvette, France; the NIST; the Österreichisches Forschungszentrum (OFS), Vienna, Austria; and the Orzagos Mérésügyi Hivatal (OMH), Budapest, Hungary. This comparison of the standards of the six laboratories show an overall agreement of 0.8%, a satisfactory level for these standards that are used primarily for radiation protection applications. This important work contributes to the harmonization of international radiation dosimetry. (P.J. Lamperti)

■ **Absorbed-Dose Calibrations and Development of Secondary Standards.** Radiation therapy has been practiced in the U.S. since the turn of the century. Approximately 500,000 cancer patients are treated annually in 1300 therapy facilities using high-energy electron or photon beams from some 2700 linear accelerators and ^{60}Co teletherapy units. In 1993, NIST completed extensive development of a water calorimeter which can realize the quantity *absorbed dose*. The changeover from in-air-kerma calibrations to in-phantom absorbed dose calibrations is a logical and necessary evolutionary step in radiation dosimetry. NIST is collaborating with AAPM TG#1 to develop a secondary standard for use by the AAPM Accredited Dosimetry Calibration Laboratories. Characterization of reference sources and ionization chambers is currently in progress. Protocols for calibration and round-robin performance testing are currently being developed. (J. Shobe and P.J. Lamperti)

■ **Alanine Dosimeter Response in Proton Therapy Beams.** The use of proton beams for radiation therapy of various malignancies is being studied at a number of institutions worldwide. Because of the wide geographic distribution of these facilities and the variety of dosimetry methods in use, there is a need for a reliable mailable dosimetry system that has a uniform response over the energy range used in proton therapy. A comparison was made of the time-dependent response of alanine dosimeters irradiated in the radiation-therapy proton beam at the Harvard Cyclotron in Cambridge, MA. Dosimeters were placed near the entrance point of the beam in the phantom and at the Bragg peak. Time-dependent changes differed slightly between these two positions. A decrease in intensity (<0.5%) over several hours was measured in the Bragg peak region after which the intensity remained constant over the next several days; dosimeters irradiated at the entrance point continued to decrease from the earliest time of measurement continuing over the course of a few days (<1%) before reaching a constant level. (M.F. Desrosiers, V. Nagy, and K. Gall)

■ **Mammographic X-Ray Exposure Standards.** The first x-ray calibrations using the NIST primary air-kerma standard for mammography were conducted in March of 1996. The parameters of the new molybdenum and rhodium beam qualities were verified including a noninvasive determination of the kVp endpoints. In assistance to other laboratories, differences in beam parameters due to changes in filtration thickness were investigated. Researchers from NIST and the University of Wisconsin-Accredited Dosimetry Calibration Laboratory (UW-ADCL) collaborated to determine appropriate transfer standards for the mammography energy range. The energy dependence of numerous ionization chambers was measured for the NIST molybdenum and rhodium beam qualities. The preliminary results of this energy dependence study were used to characterize the chambers NIST acquired for use as reference-class transfer standards. These transfer standards will be used for intercomparisons with other national laboratories and ADCLs, as well as for quality assurance of routine NIST calibrations. Initial energy dependence studies of the six newly acquired NIST reference-class mammography transfer standards were conducted. The data from these energy dependence studies has been used to assist with the establishment of guidelines for the secondary calibration laboratories, in addition to serving as the initial performance history of the new facility. (C.M. O'Brien and P.J. Lamperti)

■ **Scattered Fraction Measurements of High-energy X-rays.** High-energy photon beams from medical electron linear accelerators, used for cancer therapy, require radiation shielding of not only the direct beam but also the radiation scattered from the patient. A program for the determination of scattered dose fractions for 6, 10, 18 and 25 MeV photon beams has been taken using the NIST medical linac in MIRF. The "patient" is replaced by a cylindrical water phantom (with radius 12.81 cm) placed at the treatment position in the radiotherapy x-ray beams. Measurements were made at 200 cm from the isocenter at angles ranging from 0° to 160° with respect to the central axis of the incident beam. The ionization-chamber current measured at each angle is reported as a fraction of the ionization current measured at the center of the phantom. The results of these measurements are being compared to Monte Carlo calculations which are often used to determine shielding requirements in medical radiotherapy facilities. Secondary neutron measurements have been made at the same positions for 18 and 25 MeV beams utilizing thermoluminescence dosimeters (TLDs) placed in a 12.7 cm polyethylene moderating sphere. The results of this work is being used by an AAPM task group assigned to reappraise the design and evaluation of structural shielding for medical facilities that use high-energy x-rays. (J. Shobe)

■ **Intravascular Brachytherapy Source Dosimetry.** The use of beta-particle emitting brachytherapy sources for the prevention of restenosis (re-closing) of coronary blood vessels after angioplasty continues to be actively explored. The procedure of angioplasty is performed over 300,000 times in the U.S. each year, and in about 40% of the cases restenosis occurs, requiring another treatment. Research has shown that a dose of about 10 Gy, delivered to the wall of the blood vessel after the angioplasty has been performed, is effective in inhibiting restenosis. NIST has taken an early and leading role in the calibration of the sources used for this therapy, employing the NIST extrapolation chamber equipped with a 1 mm diameter collecting electrode to measure dose rate at a depth of 2 mm in water-equivalent plastic. These measurements are confirmed using radiochromic dye film, which is also used to characterize sources in the cylindrical geometry for transaxial uniformity. In addition, irradiation of planar sheets of film at various depths in water-equivalent plastic were used to construct data sets which can be used to predict the dose rate at arbitrary locations around the sources using a modified form of the AAPM Task Group 43 Protocol. A publication describing this work is in progress. As an example, spatial distributions of absorbed dose rate in tissue-equivalent plastic are shown in Fig. 1 for the plane, parallel to the train, at a distance of approximately 2 mm from the encapsulating surface. The plot on the left is for a train of 5 seeds with poor uniformity, that on the right for 9 seeds with good uniformity. Work for Novoste Corporation led to their being the first company allowed by the U.S. Food and Drug Administration (FDA) to have their system used to perform clinical trials. Collaborations were also begun between NIST and NeoCardia for dosimetry of a ^{32}P wire, Isotopen-Technik of Germany for the dosimetry of a ^{90}Y wire, and with Washington Hospital Center for dosimetry of various sources, including a miniaturized x-ray generating intravascular device. (C.G. Soares)

■ **Novel Approaches in Nuclear Medicine.** We are performing ongoing research projects involving several aspects of nuclear medicine, including investigations of novel methods of delivering radiopharmaceuticals. We have constructed a fullerene production apparatus and have begun incorporating specific atoms into the fullerene cage. Application of fullerenes as carriers of radioisotopes for use in cancer therapy has been suggested, but has not been studied either theoretically or experimentally. Since fullerene

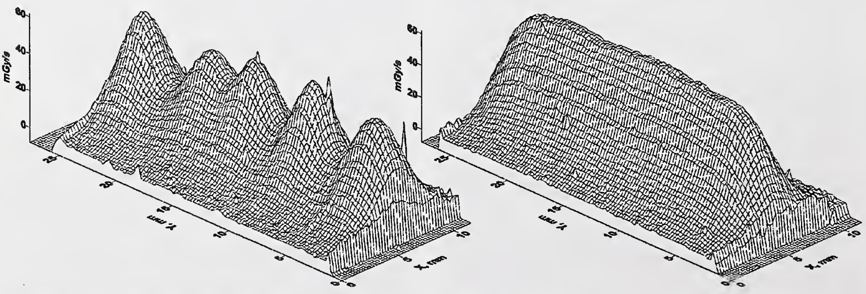


Figure 1. Dose distributions from "trains" of ^{90}Sr/^{90}Y seeds being developed for intravascular brachytherapy.

cages are capable of physically and chemically isolating radioisotopes from their associated pharmaceutical, a flexibility in choosing radioisotopes for specific tracing or therapeutic applications, not possible with currently available radiopharmaceuticals, would be possible. The successful production of radiofullerenes for cancer therapy applications would constitute a significant advance in the field of radiotherapy. The main objective of this project is the successful development of radioactive fullerenes suitable for use in medical imaging such as technetium and radioactive carbon (^{11}C). We have used the MIRF electron accelerator to convert non-radioactive ^{12}C to radioactive ^{11}C in C_{60} fullerenes obtained commercially, as well as C_{60} and larger species purified in our facility. Yield and purity of ^{11}C heterofullerenes have been determined by high pressure liquid chromatography (HPLC), multiphoton detector (MPD), liquid scintillation counting (LSC), thin layer chromatography (TLC), and Fuji phosphoimaging. In addition, we have produced, extracted and purified by HPLC fullerenes produced in the presence and absence of radioactive ^{99m}Tc and have quantified the amount of radioisotope encapsulated by MPD, LSC and Fuji imaging (after separation on TLC plates). Work has begun on encapsulation of iodine. (L.R. Karam and B.M. Coursey [with M.G. Mitch, Univ. Maryland; L. Rodriguez-Rosado and L. Laureano-Pérez, SURF])

■ **Development of Radiosensitive Dosimetric Gels.** We have prepared and done preliminary studies of radiochromic gels (gelatin containing the radiochromic dye 3,5-triphenyl-2H-tetrazolium chloride), showing the dose-coloration response to gamma irradiation. Based on those results, we have subjected similarly prepared gels to electron beam irradiation (at the MIRF) and have observed a comparable response. Gels were also provided to other laboratories for comparison in therapy type beams. (L.R. Karam, W.L. McLaughlin, P.J. Lamperti, and B.M. Coursey [with L. Francis, SURF; R. Schultz, M. Maryanski, and M. Ranade, MGS Research])

■ **Wide-Angle Free-Air Chamber for ^{125}I.** The wide-angle free-air chamber (WAFAC) will serve as the NIST standard for air-kerma-strength measurements for ^{125}I brachytherapy seeds and perhaps other low-energy photon emitters. The chamber and associated fixtures are in the process of being moved to another room. The mechanical support mechanism, source holder, and filter holder are being redesigned at this time. Redesign of the WAFAC support mechanism will allow for greater flexibility in determining the WAFAC parameters. We anticipate that redesign of the source support mechanism will reduce uncertainties due to source holder scatter and attenuation. In addition, work is in progress to automate the measurement and analysis procedure, including a motorized filter/shutter wheel. Locating the WAFAC in a separate facility will provide an opportunity for a dedicated measurement facility. (P.J. Lamperti, J.T. Weaver, and J. Shobe)

■ **Neutron Interferometry and Optics.** Since September 1996, the Neutron Interferometry and Optics Facility (NIOF) in the NIST Cold Neutron Guide Hall has been fully operational as a national users' facility, and it has a crowded schedule of experiments. One third of the beam time is reserved for NIST staff research, focused primarily on development of new techniques for materials research. The remainder of the beam time is allotted to outside users by an advisory committee, based on the merit of research proposals submitted. Experiments have already been done involving researchers from the University of Missouri-Columbia, Exxon, the Hahn-Meitner Institute (Berlin), and the Atom Institute (Vienna). These experiments have given preliminary results in phase-contrast imaging, high-resolution two-dimensional absorption imaging, neutron scattering length measurements, and testing of very large scale interferometer crystals. Most of these experiments are expected to be concluded in the next few months after receiving additional beam time.

The very keen interest of the national and international user community in this new facility arises from its unique capabilities. Two new large interferometers of NIST design have been fabricated and are being used to carry out experiments. These interferometers have novel design features allowing elimination of second-order beam contamination and operation at low neutron energies ($\sim$4 meV) which are advantageous for materials science and solid state physics research. These are the first neutron interferometers in the world that have been successfully operated at such low neutron energies. When operated at slightly higher energies, one of these interferometers achieved fringe visibility as high as 88% at the best spot and had a large area with fringe visibility exceeding 70% everywhere within. At 4 meV the fringe visibility is about 40% at the best spots. Phase stability is of the order of a few milliradians per

24 hours. The special foundation under the facility, robust vibration isolation systems, an active position stabilization system, and the special characteristics of the new NIST-designed interferometer crystals all contribute toward the achievement of these unprecedented performance characteristics.

In addition, we have initiated the development of a large scale (~20 cm diameter) neutron radiography/tomography capability. (M. Arif, D. Jacobson, A. Thompson, and T. Gentile)

■ **Development of Neutron Spin Filters by Laser Polarization of ^{3}He.** The developmental program to produce polarized neutron beams using a ^{3}He spin filter at NIST has seen major advances during the last two years. This method should yield efficient, broadband neutron polarizers that will have several advantages over conventional polarizers, both for condensed matter studies and for fundamental physics. In addition, the technology for polarizing the ^{3}He gas is applicable to the newly emerging medical field of polarized gas magnetic resonance imaging (MRI), as well as applications in basic nuclear physics.

The spin filter is based on the spin-dependent absorption of neutrons by polarized ^{3}He in the reaction ^{3}He(n,p)^{3}H. We have parallel programs to produce polarized ^{3}He either by (1) spin-exchange with optically pumped rubidium vapor or (2) direct optical pumping of metastable ^{3}He followed by mechanical or cryogenic compression of the low pressure gas. Progress in each program will be discussed separately below.

Spin-Exchange Based Spin Filter: Milestones passed in the last two years include optimization of ^{3}He polarization using the Ti:Sapphire laser, conversion to use of inexpensive diode laser arrays for optical pumping of Rb, construction of a cell filling station, production of cells with properties required by a real polarizer, and initial testing of cells on a neutron beam. Work has begun on a medical imaging spin-off of this technique.

A ^{3}He polarization of 25% was measured in the spin-exchange setup early in 1995 using the Ti:Sapphire laser. Later in 1995 we measured 15% polarization using a laser diode array. The diode laser requires higher density ^{3}He for optimal performance, so we have constructed a cell filling system and a new oven to better match the properties of the diode laser. The filling system was commissioned in April of this year, and we have produced multiple cells with long lifetimes (some near 200 hours). In the summer of 1996 we tested some of the cells on the polarized neutron beam at the end of NG-6 at the Cold Neutron Research Facility. Results from these tests are guiding the design of improved cells and the choice of cell materials. The new materials have been ordered and we expect to have a viable spin filter cell within the next few months.

In April 1996 we were contacted by a researcher at the University of Pennsylvania regarding MRI of lungs using polarized ^{3}He. In collaboration with the Medical Imaging Group at Pennsylvania, we have produced multiple cells containing roughly one liter of polarized ^{3}He, and produced initial images of a volunteer's lungs, which are almost impossible to image using traditional MRI techniques.

Metastability-Exchange Based Spin Filter: In the metastable method, the gas is polarized at a pressure of ~1 torr, and then must be compressed up to a pressure of ~1 bar for use as a neutron polarizer. Maintaining the polarization during compression is a technical challenge, but has been achieved by a group in Mainz, Germany using a two-stage piston compressor. We are developing a similar compressor in collaboration with Indiana University. Our collaborators at Indiana have designed this apparatus, and NIST is assisting with the construction of their optical pumping system. In addition, we are investigating an alternate compression apparatus based on modification of a commercial diaphragm pump. Success in this alternate approach could yield a compact, simple apparatus that would allow very economical development of the metastable method for neutron polarizers and other applications. The apparatus for optical pumping of ^{3}He at low pressure has been constructed and 80% polarization has been obtained. (A. Thompson, T. Gentile, G. Jones, and F. Wietfeldt)

■ **The Neutron Lifetime and Asymmetries of the Weak Interaction.** The NG6 End Station in the Cold Neutron Guide Hall is operated as a national users' facility for fundamental neutron physics, under the supervision of the same advisory committee mentioned above in regard to the NIOF. Experiments at this beam station are focused on testing aspects of the standard model of particle interactions which are accessible from precise measurements of neutron interactions and decay.

For a number of reasons, including two longer-than-expected shutdowns of the NIST research reactor, the neutron lifetime experiment had to be taken off-line temporarily to allow beam time for two other weak interaction experiments which were ready to run. The neutron lifetime experiment at NIST collected data during two separate periods, 10/93-5/94 and 11/95-5/96. This difficult experiment which had run with some success in Grenoble previously, has had more serious difficulties in the attempts to improve on or even reproduce the Grenoble results at NIST. Investigations of several possible causes of these difficulties are in progress off-line while the initial runs are made for the two other experiments: Parity-Non-conserving Spin Rotation in Liquid Helium and the emiT Experiment, a search for time-reversal asymmetry in neutron beta decay.

Parity-Non-conserving, Neutron Spin Rotation in Liquid Helium: This experiment concerning details of parity violation is primarily the work of a team from the University of Washington, Seattle (D. Markoff, S. Penn, B. Heckel, and E. Adelberger). NIST physicists have been involved in preparation of the supermirror polarizer and analyzer for this experiment, as well as other aspects of beamline preparation and shielding; the polarization achieved was 96%. This experiment collected useful data intermittently during 9/96-11/96, but suffered frequent outages for recovery from cryostat problems. The data obtained will be marginal statistically for setting a significant bound on the spin rotation per unit length of travel. A future run with an improved cryostat is expected.

The emiT Experiment: This very large collaboration involves physicists and engineers from the Univ. of Washington, the Lawrence Berkeley Laboratory, the Univ. of Michigan, Los Alamos National Laboratory, and NIST. This experiment uses the same supermirror polarizer arrangement as the spin rotation experiment. The experiment will run for about 20 weeks beginning in December of 1996.

Two more experiments besides conclusion of the beam-type neutron lifetime experiment are in the planning stages for 1997. An ultracold neutron, bottle-type lifetime experiment with collaborators at Harvard University is in preparation, with an initial run expected in 1997. A repeat of a Russian spin-antineutrino asymmetry experiment is also likely to be allocated beam time. NIST staff participated in an initial run of this experiment in Grenoble in the summer of 1996. (F. Wietfeldt, J. Nico, D. Gilliam, J. Adams, and G. Jones)

■ **Neutron Dosimetry for Reactor Safety Assessment.** Through a cooperative agreement with the Office of Nuclear Regulatory Research, NIST provides measurement assurance services and consultation related to neutron dosimetry and nuclear reactor safety. After many years of NIST consultation with experts from industry and national laboratories, the Draft Regulatory Guide DG-1053 (formerly DG-1025), *Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence*, was issued in essentially final form with very little objection from the major reactor vendors or regulated utilities. NIST will continue to support the measurement assurance steps called for in this guide to keep the national measurement system on track in this field. Consultation issues have begun to go from the generic case to plant specific cases, as aging nuclear electric power plants are nearing levels of cumulative neutron radiation exposure which could be of concern regarding the risk of brittle fracture of a pressure vessel under certain extreme conditions. NIST also has carried out and published research on fission neutron transport through thick steel sections to test the relevant nuclear data files employed in calculations for assessment of reactor safety. (J. Adams, E. D. McGarry, J. Nico, and J. Grundl)

■ **Nuclear Cross Section Standards.** Nuclear cross section data standards are important for nuclear reactor safety and performance calculations, development of fusion energy, understanding accelerator neutron source dosimetry, and basic studies in astrophysics. The NIST program in support of these nuclear data standards has been substantially reduced in scope in recent years, and the emphasis of the remaining program has shifted from measurements to evaluation and international coordination of standards efforts. NIST performs its role in motivating and coordinating new standards measurements by examining the standards data base, pursuing the extension of the standards over a larger energy range, and leading efforts directed toward new evaluations of the standards. These efforts have taken place largely through participation in the Cross Section Evaluation Working Group and our international involvement through the Nuclear Energy Agency Nuclear Science Committee and the International Nuclear Data Committee. Continuing experimental collaborations include an effort at the Ohio University Tandem Accelerator to refine the angular distribution data for the very important hydrogen scattering cross section standard. (A. Carlson and R. Schrack)

■ **Dissemination of National Standards of Radioactivity.** The Radioactivity Group disseminated the national standards of radioactivity mainly through the following three activities:

(1) Over 700 radioactivity standard reference materials (SRMs) were provided. (2) Over 200 comparative measurements and reports of traceability were provided 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 four research associates in cooperative testing programs. (3) Over 60 calibrations of customer sources were provided. (L.L. Lucas, J.C. Cessna, and J.M.R. Hutchinson)

■ **Glow-Discharge Resonance Ionization Mass Spectrometry.** Work continued on the development of a glow-discharge initiated mass spectrometer system which would permit the direct compositional analysis of soils and sediments for radioactive and non-radioactive trace elements. For effective radioassay, a sensitivity in the range of 10^{-13} is useful for most environmental contaminants. A continuous wave titanium-sapphire (Ti-Saph) laser was incorporated into the system to perform initial highly selective Z discrimination before isotopic selection in the mass spectrometer. Preliminary tests of this system have been performed. (J.M.R. Hutchinson)

■ **Natural Matrix Standards.** In October 1977, the International Committee for Radionuclide Metrology sponsored a symposium at Woods Hole, Massachusetts to define needs and initiate programs to develop natural matrix radioactivity standards. The term "natural matrix standard" (NMS) refers to a standard of radioactivity which is homogeneously contained in a matrix, such as soil or vegetation, in the same chemical forms as are found in the environment. Since that time six NMSs have been issued: River Sediment, Human Lung, Human Liver, Rock Flats Soil #1, Freshwater Lake Sediment, and Peruvian Soil.

Three more are under development as follows:

■ Over the past decades, on the order of 10^{15}Bq nuclear waste have been stored in the oceans. Potential contamination of the oceans from leaking nuclear waste has caused worldwide concern. Because the determination of low-level radioactivity in ocean sediment is a difficult technical task, a basis for measurement quality assurance, methods verification, and data comparability is needed. The NIST ocean sediment Standard Reference Material (SRM-4355) is being developed using a composite of 1% contaminated Irish Sea sediment and 99% Chesapeake Bay sediment by weight. Twelve radionuclides including ^{40}K, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, ^{235}U, ^{238}Pu, and $^{239\text{-}240}$Pu were certified. The mean values were reported for an additional 10 uncertified radionuclides: ^{129}I, ^{155}Eu, ^{210}Po, ^{210}Pb, ^{212}Pb, ^{214}Pb, ^{214}Bi, ^{228}Ra, ^{237}Np, and ^{241}Am. The standard reference material in unit quantities of about 100 gm each will be available by the end of 1996.

■ The second standard for ocean studies is dried shellfish flesh. Shellfish is a material widely assayed for radionuclide content because it is a bioaccumulator and is part of the human diet. Approximately 350 kg of dried shellfish from the western Pacific Ocean, Irish Sea and White Sea are now available for processing. Interlaboratory comparisons are being planned with international expert laboratories for 1997.

■ Bone as a sink of a number of long-lived radionuclides is a key organ for biokinetics model development and dosimetry studies. Development of a bone standard for the bone-seeking radionuclides is one of the most important tasks in ensuring quality control in bone sample analysis and for providing a common basis for data comparison and evaluation. The development of a bone ash standard for low-level radioactivity measurements provides a great analytical challenge in radiochemistry because of its high calcium and phosphate content. The standard is being characterized for ^{90}Sr, ^{210}Pb and U, Th and Pu among international radiobioassay expert laboratories. (K.G.W. Inn and Z. Lin)

■ **Chemical Speciation of Environmental Radioactivity.** The primary concerns associated with radionuclides in the environment are: (1) migration through natural systems; and (2) bioavailability *via* the food chain. The problem is that ionizing radiation in sufficient doses can affect a variety of processes in higher organisms. Since the mobility and bio-availability of radioactive elements in the environment must be dependent upon the element's chemical speciation, the characterization of the element's physico-chemical forms in soils and sediments is a key factor in understanding and predicting the migrational behavior of trace metals and radionuclides. One widely used empirical approach for describing speciation is the application of sequential-chemical extractions.

NIST is now exploring the possibility of certifying Standard Reference Materials (SRMs) for soils and sediments by "fraction" as well as for "total" concentration as indicators of the bioavailability of radionuclides in the environment. A statistical, experimentally designed, sequential leaching, radiochemical separating, and low-level beta-particle counting procedure has been designed and will be carried out in collaboration with Florida State University to establish a reference method. The seven-step extraction procedure will be optimized for Pu, U, and ^{90}Sr from the following fractions: exchangeables, carbonates, reducibles, organics, iron and manganese oxides, acid leachables, and silicates. Four experimental conditions (reagent concentration, pH, duration of extraction period, and temperature of reaction) were identified as potentially significant parameters. The study will begin by optimizing the method using SRM 4357 (Ocean Sediment). (K.G.W. Inn and M. Schultz)

■ **Photo-nuclear Produced Radioactivities.** The MIRF facility has been used to produce positron emitting radioactivities. Techniques have been developed to characterize those sources. Efficiencies for positron emission, which have been stopped and annihilated, have been developed and compared, when appropriate, with associated gamma-ray emission from the decay. Radioactivities characterized this last year included ^{126}I, ^{18}F and ^{34m}Cl. The last radionuclide is of particular interest as a high gamma-ray energy emission rate standard for Ge detector calibration. ^{34m}Cl has a 3303.6 keV gamma-ray with a probability per decay of 0.123. This abundant emission and readily prepared radioactivity allows the extension of the current efficiency curve to that energy. (F.J. Schima)

■ **^{63}Ni Standardization and Decay Studies.** Standard solutions of ^{63}Ni have recently been prepared and were disseminated as NIST SRM 4226C. The solutions were calibrated by $4\pi\beta$ liquid scintillation (LS) spectrometry with ^{3}H-standard efficiency tracing. This radionuclide is of interest to the nuclear reactor community because it is often found in reactor environments as the neutron activation product of nickel present in the steel used in construction of those facilities. Certain physical properties, namely a low β^- energy (66.945 ± 0.004 keV) and a relatively long half-life (101.1 ± 1.4 a) also make it attractive for radionuclidic metrology studies, as it tends to be a more sensitive indicator of effects in measurement technique and procedures than would a radionuclide with a higher β^- energy. This SRM is gravimetrically related to two others previously prepared by NIST/NBS (SRM 4226, prepared in 1968 and calibrated by microcalorimetry, and SRM 4226B, prepared in 1984 and calibrated with $4\pi\beta$ LS spectrometry with ^{3}H-standard efficiency tracing). This allows a comparison to be made between the three sources as a check of both measurement consistency and solution stability. After adjusting the data from the 1968 and 1984 measurements to include the latest available nuclear data for both ^{63}Ni and ^{3}H, we found the three measurements to be in agreement to within 0.3%. Because of this remarkable consistency over a 27 year span, the three data sets provided enough data to make the first-ever determination by radioactive decay of the ^{63}Ni half-life. Using these data, we determined the half-life to be 101.06 ± 1.97 a. A critical review of measurements of the ^{63}Ni half-life was performed, resulting in a new recommended value of 101.1 ± 1.4 a. A series of articles addressing all of these topics has been published (see Appendix A). (B.E. Zimmerman and R. Collé)

■ **Final Results for the International Intercomparison of Marine-Atmospheric Radon Measurements.** The importance of various kinds of high quality radon measurement data to the world's atmospheric transport modelers was identified in the preceding highlight. In 1991-1992, NIST conducted an *in situ* calibration and intercomparison exercise for marine atmospheric radon measurements. The participating laboratories have been responsible for perhaps 95% of the available surface-level measurements gathered around the globe over the last decade. The results of this intercomparison exercise have at last been fully published in a series of articles that appeared in the *Journal of Geophysical Research* and *Journal of Research of NIST*. The intercomparison utilized a common standardized, *in situ*, reference basis (provided by NIST) that could be directly related to U.S. national, and internationally, recognized, ^{226}Ra and ^{222}Rn standards, and evaluated the performance of all principal instruments that are used to measure radon activity concentrations for marine-atmospheric studies. The findings will assist various users in the global modeling community in applying the available and future radon measurement data bases in a more reliable and effective manner. The work went beyond serving the needs of just this particular intercomparison. It also demonstrated the broader utility of the developed procedures, i.e., the calibration protocol and the methodology for providing *in situ* standardized samples. Most environmental measurement intercomparisons of field instruments in actual use merely rely on evaluating the relative performance of the participants, or some comparison to the pooled results. This exercise demonstrated, for the very first time, the capability of providing a standardized reference basis even for such low-level, field-measurement intercomparisons. The developed methodologies could be adopted with slight modifications to cover other radon concentration ranges and other applications, and could be employed in many other types of radon environmental field-measurement intercomparisons. (R. Collé)

■ **International Intercomparison of ^{63}Ni and ^{55}Fe.** The Radioactivity Group recently participated in an international measurement intercomparison for ^{63}Ni and ^{55}Fe, which was conducted amongst principal national radionuclidic metrology laboratories. The intercomparison was sponsored by EUROMET, and was primarily intended to evaluate the capabilities of liquid scintillation spectrometry techniques for assays of nuclides that decay by low-energy β^- emission (like ^{63}Ni) and by low-Z (atomic number) electron capture (like ^{55}Fe). Preliminary results from this intercomparison reveal an excellent agreement for ^{63}Ni between the NIST finding and those from other participating laboratories. The results for ^{55}Fe suggest that we need to conduct rigorous, systematic evaluations of our LS capabilities in assaying radionuclides that decay by low-Z electron capture. (R. Collé and B.E. Zimmerman)

■ **Liquid Scintillation Spectrometry Intercomparison of Tritiated Water Standards.** Radioactivity standards of tritiated water (^3H_2O) – disseminated by the LPRI and the NIST, the national radionuclidic metrology and standardization laboratories of France and U.S.A., respectively – have been intercompared by liquid scintillation (LS) spectrometry. The ratio of the certified massic activities for the two standards was compared to that obtained from direct measurements on matched sets of LS cocktails prepared from the standards. Seven experimental trials (involving a total of 21 counting sources for each standard) were performed for the comparison. The trials were performed under a wide range of experimental conditions, including use of two different LS spectrometers and three series of LS cocktail compositions (with systematically varied ^{3}H detection efficiencies). The results exhibited an apparent mean disagreement between standards of less than 0.4% on a relative basis. For contrast, the relative combined standard uncertainty on the massic activity ratio for the two standards, as obtained from their respective certified uncertainty assessments, is about 0.7%. A paper on these results was published in *Applied Radiation Isotopes.* (B.E. Zimmerman and R. Collé)

■ **Development of Standard for the Palliative Therapy Radionuclide ^{117m}Sn.** As part of an increasingly active program to develop national standards for radionuclides of interest to the nuclear medicine community, this group has recently performed a calibration of ^{117m}Sn, which is currently under study for use in palliative therapy for pain associated with metastatic bone cancer. The calibration was performed using three techniques: γ-ray spectrometry with HPGe detectors, γ-ray spectrometry with a 4π 30 cm NaI(Tl) system, and $4\pi\beta$ liquid scintillation (LS) spectrometry. Data were obtained using HPGe spectrometry to confirm the probability per decay of the major emissions. A procedure for the direct standardization of this isomeric radioactivity based on sum coincidence peaks is underway. This procedure would allow calibration of ^{117m}Sn sources using an HPGe detector with adequate resolution. Data were also obtained for the re-determination of the half-life using all three detection systems and included an additional measurement using the NIST ionization chamber. The half-life was found to be 19.98 d$\pm$0.04, the weighted average of the LS, HPGe, NaI(Tl), and ionization chamber measurements. This value is 3% higher than the ENSDF-recommended value, which is based upon a single measurement. Our evaluation of all ^{117m}Sn half-life measurements, including our new data, indicates that the ENSDF recommendation is an outlier.

This radionuclide is particularly exciting because of the greater uptake of ^{117m}Sn(4+) DTPA in bone tissue relative to the marrow. Compared to other commonly-used bone palliation radionuclides such as ^{89}Sr, ^{32}P, and ^{186}Re, there is as much as a 4-fold increase in the ratio of bone-surface dose to bone-marrow dose with the use of ^{117m}Sn(4+)DTPA. This suggests that a much higher dose can be given to the patient before marrow toxicity levels are reached, possibly leading to the ability to treat the metastases themselves. An additional advantage in using ^{117m}Sn is the presence of a 159 keV γ-ray, which allows the uptake and distribution of the radionuclide to studied with conventional imaging devices. (B.E. Zimmerman, J.T. Cessna, F.J. Schima, and M.P. Unterweger)

■ **Calibration of Large-Area Beta Sources.** Calibrations of the $2\pi\beta$ emission rates and measurements of homogeneity of several large area sources have been completed. The effects of β-backscattering are under investigation in order to provide accurate values of activities of these sources for use in calibrating β field monitors. These investigations include comparison of these measurements with Monte Carlo calculations performed by Martin Berger. In addition, a method has been developed to estimate the effective source thickness, an important parameter in relating the measured rate to the activity. (M.P. Unterweger and P. Hodge)

■ **Iodine-129.** ^{129}I is a very long-lived (the half life is 15 million years) fission product that can be significantly concentrated by some organisms. Hence there is interest in monitoring this radionuclide in food and in the environment. Isotopically-enriched ^{129}I was obtained from the Oak Ridge National Laboratory. This material contains approximately 96 atom-percent ^{129}I. The activity was calibrated by $4\pi\beta$(LS)-γ-anticoincidence counting and the material is now available as Standard Reference Material (SRM) 4949C. (L.L. Lucas)

■ **Iron-55.** ^{55}Fe is a radionuclide with a half life of 2.9 years that is produced with great efficiency whenever iron is irradiated with neutrons. It is a very common byproduct of reactor operation. ^{55}Fe decays by electron capture and emits only low-energy (5 keV) x-rays. Hence, its calibration is more difficult than most of the radionuclides for which standards are issued. The massic activity is being measured in the NIST 4π(e + X)-γ-anticoincidence counting system using ^{54}Mn as the efficiency-tracing radionuclide. The half-life data are being reevaluated and SRM 4929E will be issued shortly. (L.L. Lucas)

■ **Cesium-137.** ^{137}Cs is a long-lived (the half life is 30 years) fission product that is used as a gamma-ray source for irradiation and detector calibration and as a fission monitor for nuclear fuel. For this reason, SRM 4233 and its subsequent reissues have been certified in terms of both activity and number of ^{137}Cs atoms. The ^{137}Cs massic activity was measured in the NIST 4π(e + X)-γ-anticoincidence counting system using ^{134}Cs as the efficiency-tracing radionuclide. The massic number of ^{137}Cs atoms was measured by isotope dilution mass spectrometry using ultra-pure ^{133}Cs as the diluting isotope. The latest reissue of this standard is now available as SRM 4233D. (L.L. Lucas)

FUTURE OPPORTUNITIES

■ **Industrial High-Energy Computed Tomography.** The MIRF electron linear accelerator should provide an adequate source for a test bed for high-energy CT applications. With past and current experience applications in low- and high-energy CT, the establishment of capabilities at MIRF would provide a valuable resource to pursue collaborations in innovative areas such as studies of the solidification front in metal castings, a subject for which we have been approached. The construction of a high-energy x-ray camera system, scheduled for this year, will help position us to contribute in such studies.

■ **Radiofullerene Tracer Development.** Based on the progress to-date on the development of radiofullerenes, NIST should soon be poised to produce radioendofullerenes, based on a variety of useful radionuclides, for applications as tracers in biomedical, materials and process studies. The potential advantage, particularly for biomedical applications, is the rather complete chemical and biological isolation of the chosen radionuclide in the fullerene nano-chamber which, along with the ability to attach site-specific molecules to the fullerene cage, will provide for far greater flexibility in constructing an effective radiopharmaceutical than is presently available. The availability of the MIRF electron linear accelerator, the NIST reactor, and the resident expertise in our division provides a strong base for such development.

■ **Brachytherapy Dosimetry.** An estimated 60,000 brachytherapy procedures are currently performed annually in the U.S., with the potential to increase to 500,000 with the advent of intravascular brachytherapy in the treatment of heart disease. Critical to the quality assurance of absorbed dose measurements in such procedures is traceability to national standards. We have provided early leadership in the dosimetry of beta-emitting brachytherapy sources, and now we should develop a coherent program for the measurement of absorbed dose in water or tissue for all such sources, including photon-emitting radionuclides.

■ **Industrial Electron-Beam Dosimetry Calibrations.** Radiation processing by electron beams with energies from about 0.1 to 25 MeV are carried out in an estimated 700-1000 facilities, with such use on an increasing path. With the MIRF electron accelerator capable of beam energies of 7 to 32 MeV, and the electron Van de Graaff, with energies from 1 to 4 MeV, NIST has the resources to address the need for the direct electron-beam calibrations and traceable reference measurement services for much of the range involved in industrial processing.

■ **Magnetically Trapped Ultra Cold Neutrons.** In collaboration with physicists at Harvard University an Ultra Cold Neutron (UCN) experiment is planned, based on "superthermal" cooling of neutrons with wavelength 0.89 nm to the ultra cold neutron energy range by exchange of a single phonon (per neutron) in a superfluid bath of liquid helium. The initial application of this UCN source will be a neutron lifetime experiment with potential improvement in accuracy of better than a factor of 10 compared to the present best value.

■ **Neutron Tomography.** Recent improvements in CCD imaging systems and the widespread availability of computed tomography (CT) and 3D image reconstruction software have made it possible to set up a neutron CT imaging system with only modest resources. Neutron CT imaging can complement x-ray CT scans by providing higher sensitivity to hydrogen, boron, lithium and certain other elements and isotopes in many important industrial applications.

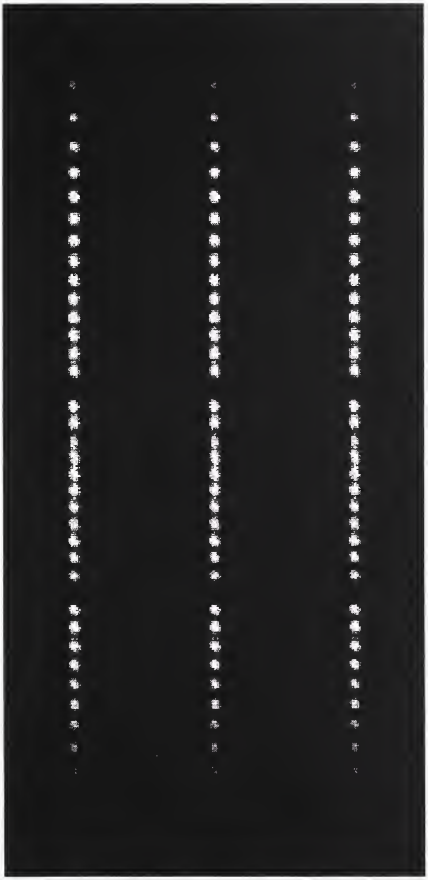
■ **Laser Polarization of Neutrons.** Commercial developments in the production of inexpensive diode lasers may make laser polarization of neutrons by spin exchange the method of choice for both materials science and neutron physics experiments. However, research in non-perturbing compression of low density polarized ^3He from direct optical pumping of metastable ^3He may lead to an even less expensive method. Both possibilities are being pursued. The application of laser-polarized inert gases to medical magnetic resonance imaging is also being investigated through a collaboration with the University of Pennsylvania.

■ **Development and Calibration of Very-low Level Measurement Techniques.** (i) A fast, inexpensive method for atom counting based on Resonance Ionization Mass Spectrometry will continue to be developed. Although much progress in this program has been made, the sensitivity must be improved by increasing the duty cycle. A Ti(Saph) laser is being adapted for this application. (ii) The Nuclear Regulatory Commission is moving toward increasing sensitivity requirements for *in situ* measurements of radioactivity by a factor of 10 from that which can be attained by the present Ge-based systems. NIST will investigate and develop imaging plate technology for the measurement of very low level activities in site remediation, in breakdown in microchips by alpha particle contaminants and other areas.

■ **Radiopharmaceuticals and Nuclear Medicine.** National laboratories, universities, and radiopharmaceutical companies report that they are investigating about three dozen potential radiopharmaceuticals. In many cases, the decay scheme and calibration data are suspect. In order to facilitate licensing of these materials, NIST must provide the necessary calibration data and accompanying measurements prior to Food and Drug Administration approval. The Radioactivity Group will continue to collaborate with researchers in the early phases of radiopharmaceutical development to hopefully decrease the amount of time necessary to complete the approval process.

■ **Traceability for Low-level Radiochemistry Metrology.** Many tens of thousands of low-level radiochemical measurements are made annually to support environmental remediation and occupational health programs. The credibility of these measurements have been based on participation in regulation driven performance evaluation programs of limited scope. The fundamental flaw that the metrology community recognizes is that there is a lack of direct linkage to the national radioactivity standards. This situation is being addressed in the publication of three ANSI Standards. These three consensus standards call for a traceability testing program that links the quality of operational measurements to the national standards. The Radioactivity Group is planning a user group workshop for early January 1997 to establish such a traceability testing program for low-level radiochemistry. Laboratories expressing early interest include: Westinghouse Carlsbad, University of New Mexico at Carlsbad, Sandia National Laboratory, and EPA Montgomery. Initially, it is anticipated that the program will include both the environmental restoration and radiobioassay communities. □

TIME AND FREQUENCY DIVISION



Overleaf

Image of Mercury Ions in a Linear Electromagnetic Trap. This picture shows three identical images of the same string of trapped ^{199}Hg ions being studied as a possible atomic frequency standard. The ions are illuminated with radiation at 194 nm and fluoresce to produce this image in a special ultra-violet imaging system. Studies involving both microwave and ultra-violet transitions indicate strong potential for higher-accuracy frequency standards. The gaps in the string result from the presence of impurity ions, most likely other isotopes of mercury that do not fluoresce at the same frequency as does ^{199}Hg.

TIME AND FREQUENCY DIVISION

MISSION

The mission of the Time and Frequency Division is to support U.S. industry and science by providing measurement services and research in time and frequency and related technology. To fulfill this mission the Division engages in:

- development and operation of standards of time and frequency and coordination of them with other world standards;
- development of optical frequency standards supporting wavelength and length metrology;
- 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.

The work supporting length metrology derives from the definitional dependence of the meter on the second. This Division work contributes to a larger program in the Precision Engineering Division (MEL), which has primary responsibility for length and its dissemination.

ORGANIZATION

The Division is organized into eight technical Groups: Time & Frequency Services, Time Scale & Coordination, Cesium Standards, Ion Storage, Phase Noise Measurements, Laser Spectroscopy, Optical Frequency Measurements, and Network Timing. 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 among the Groups. During 1995 and 1996, the Division hosted 44 guest researchers and 12 postdocs.

CURRENT DIRECTIONS

■ **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 NOAA's GOES weather satellites. Last year, the Division initiated an effort to upgrade the equipment and power level for WWVB. At a somewhat higher output power, these LF broadcasts could become substantially more useful for mobile and consumer applications, because the antenna/receiver cost and size would be very small. The Division also operates telephone and network time services, including the Automated Computer Time Services (ACTS), designed for setting clocks in digital systems. The network (Internet) service is the newer of the two and already receives nearly 200,000 calls per day. These broadcasts serve applications in a broad range of systems in business, telecommunications, science, transportation, and radio/TV broadcasting. Industry calibration laboratories are served by the Division's Frequency Measurement Service, a system that provides these laboratories with continuous assurance of the accuracy of their frequency measurements.

■ **Improved Time Scales.** The NIST Time Scale is the flywheel clock system that provides accurate signals for services and applications and that 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 under the control of a computer-implemented algorithm. The Division is working to improve the performance of the time scale by acquiring more-stable clocks and improving electronic systems that read the clock outputs. These improvements are critical to the successful evaluation and use of the next generation of primary standards now being developed by the Division.

■ **New Frequency Standards.** The accuracy of the time scale is derived from primary frequency standards that provide the practical realization of the definition of the second. To meet advancing needs, the Division built a new frequency standard, NIST-7, which went into operation in early 1993. This atomic-beam standard is based on optical pumping methods (using diode lasers) rather than the traditional magnetic methods used for state selection and detection. The current uncertainty for this standard is 5×10^{-15}, but further improvement in evaluation methods should allow for improvement perhaps to the level of 1 or 2×10^{-15}. The Division is constructing a new cesium-fountain frequency standard that should be in operation within the next year (this work is joint with the Atomic Physics Division). Looking toward still higher accuracy, the Division is studying standards based on trapped, laser-cooled atomic ions. Ion standards 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, 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 improve the Two-Way Time Transfer Method which promises still higher transfer accuracy. A two-way link to Europe has been implemented, and another two-way link to the Pacific region is under development.

■ **Improved Optical Frequency Standards.** The Division is also engaged in developing improved optical frequency measurements important for primary frequency standards, secondary wavelength standards based on atomic-and-molecular transitions, advanced optical communication, analytical instrumentation, and length measurement. There are several facets to this program. There is of course the interest in developing future primary frequency standards based on optical transitions, since in general, higher frequency transitions yield a better fractional-frequency uncertainty. Another area of effort is on diode lasers which can have very high spectral purity, tunability, simplicity, and low cost. The approach taken in this work is to prove concepts through demonstration of working systems. The Division also develops accurate optical frequency and wavelength references such as the CO_2 laser and the calcium-stabilized diode laser. Such frequency references serve as standards in making accurate spectroscopic measurements in industrial and scientific programs. The program has recently been expanded to include a responsibility for developing advanced optical-frequency standards to support improved length measurement and standards.

■ **Development of Improved Spectral-Purity Measurements.** The Division's development of new spectral-purity measurements supports sound specifications for a range of aerospace systems. Systems capable of making highly accurate measurements of both phase-modulation (PM) and amplitude-modulation (AM) noise have been developed for carrier frequencies ranging from 5 MHz to 75 GHz. Portable systems covering this same range have also been developed and these are being used to validate measurements made in industrial and government laboratories. Further work will broaden the spectral coverage and simplify comparison of measurement accuracy among standards laboratories. New PM and AM calibration services have been brought into operation over the last several years.

■ **Synchronization for Telecommunications.** The Division has been actively engaged with the telecommunications industry in issues relating to synchronization of advanced generations of telecommunications networks. NIST has made useful contributions to emerging telecommunications systems, but with expansion of effort by the Division, it is clear that NIST could contribute even more significantly to this industry. The industry has requested such expansion. The Division is working through the initiative process to increase base funding in this area.

■ **Application 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 quantum-limited measurements.

TECHNICAL HIGHLIGHTS

■ **Rabi Pedestal Shifts as a Diagnostic Tool in Primary Frequency Standards.** Jon Shirley, David Lee, and Bob Drullinger of the Time and Frequency Division in Boulder, in collaboration with Daniel Rovera of the Laboratoire Primaire du Temps et des Fréquences in Paris, have developed a new method for evaluating certain systematic frequency shifts in primary cesium frequency standards. They use a digital servo system to measure the frequency offset between the Rabi pedestal and the Ramsey fringe for all seven components of the hyperfine transition observed in a cesium-beam standard. Measurement of the dependence of each of these shifts on microwave power enables them to separate three distinct causes: Rabi pulling, cavity pulling, and magnetic field inhomogeneity.

The method was used to evaluate these three shifts for NIST-7, NIST's new optically pumped cesium-beam frequency standard. The method indicates a shift due to magnetic-field inhomogeneity of 2×10^{-15}, a shift due to cavity pulling of 6×10^{-15}, and a shift due to Rabi pulling of less than 1×10^{-16}. One advantage of the method is that it requires frequency measurements no better than 1×10^{-11} to evaluate these exceedingly small frequency biases. This work is part of a continuing effort to find additional independent methods for measuring each of the systematic errors in NIST-7. The shifts measured in this manner are consistent with previous measurements using other methods, and add confidence to the NIST-7 uncertainty statement which is now 5×10^{-15}.

This and other new evaluation methods hold the potential for improving accuracy, perhaps by a factor of five. This means that the original goal of an improvement of a factor of ten could be extended to a factor of one hundred, producing the largest performance advance for any frequency standard constructed at NIST. These advances give NIST a more comfortable margin over commercial frequency standards which are now approaching uncertainties of 1×10^{-13}. (R. Drullinger)

■ **Electronic Control Systems for Primary Frequency Standards.** David Lee and Craig Nelson are developing completely new electronic control systems for NIST-7. While their first system will be specific to NIST-7, their design philosophy provides for an evolution that can support future standards such as cesium-fountain and linear-ion-trap frequency standards. The design brings together four work stations interconnected with a local optical-fiber network. The fiber connections dramatically reduce problems associated with electrical ground loops bringing substantially more order to the overall grounding of the different components of the standard.

The hardware changes are the most visible aspect of this advance, but perhaps the most important progress in the new system is the introduction of object-oriented programming techniques in the software. Using these techniques, software objects such as microwave frequency synthesizers, digital c-field supplies, and cesium-oven controllers are developed to perform the various functions needed to run the standard. These software objects are not specifically designed around a given piece of hardware, but rather define the very general functionality of the object. The software objects interact with the hardware components through device drivers. Thus, new or different hardware components can be introduced without major rewriting of software. This will greatly simplify development work on future frequency standards. Furthermore, the objects can communicate with each other through the network, so that interactions among the various components can be easily reconfigured. One benefit of this work is that new concepts for evaluating errors or modifying the mode of operation of the standard can be tested quickly, since little effort is needed to implement such changes. (D. Lee)

■ **Development of a Cesium-Fountain Frequency Standard.** A cesium-fountain frequency standard has been designed and is now under construction in a collaborative effort involving staff of the Time and Frequency Division and the Atomic Physics Division as well as staff of the Politecnico di Torino and the Istituto Elettrotecnico Nacionale Galileo Ferraris (also in Torino). An agreement between NIST and the two Italian institutions formally establishes the international collaboration. The end point of this work will have two fountain standards at NIST and one at each of the two Italian Institutions. Bob Drullinger, Fred Walls, Tom Parker, Steve Jefferts, David Lee, Jon Shirley, Leo Hollberg, Don Jennings, and Dawn Meekhof of the Time and Frequency Division are now assembling the first of these devices in Boulder. This should be in preliminary operation by early summer. Steve Ralston and Bill Phillips of the Atomic Physics Division are studying a new method for transverse cooling. If successful, this cooling method might then be incorporated in the Boulder standard allowing for operation at a higher flux without serious collisional effects. Andrea DeMarchi of the Politecnico di Torino has been involved with the design, particularly that of the microwave cavity.

This new standard operates by launching laser-cooled cesium atoms vertically through a microwave cavity. Then, under the influence of gravity, they fall back through the same cavity allowing Ramsey-type interrogation without the usual end-to-end cavity phase shift. The atoms move more slowly than those in an atomic beam standard, so the Doppler shifts are much lower. Furthermore, the long observation time results in a narrower linewidth. This standard should operate with an uncertainty of less than 1×10^{-15}, and has the advantage of using the same time-defining transition as is used in present cesium-beam standards. (R. Drullinger)

■ **Frequency Synthesizers for Primary Frequency Standards.** Over the last several years Fred Walls of the Division has developed a state-of-the-art synthesizer design that should prove useful for the next several generations of primary atomic frequency standards. These new generations of standards demand exceptionally low-phase-noise sources for interrogation of the clock transition. His synthesizer exhibits a fractional frequency stability of 1×10^{-16} at 20 min and 1×10^{-17} at 1 day. This should be more than adequate for all frequency standards now under development. The synthesizer is being used on NIST-7 and the linear ion standard, and it will be used for cesium-fountain projects in both the Time and Frequency Division and the Atomic Physics Division. Copies of the synthesizer have also been delivered to the Naval Research Laboratory and to a standards laboratory in Brazil, and four more synthesizers are being constructed for standards projects in other countries. (F. Walls)

■ **A 100 MHz Timing Distribution Amplifier.** Fred Walls, in collaboration with Marco Siccardi, Stephania Römisch, and Andrea De Marchi of the Politecnico de Torino in Italy, have developed a 100 MHz frequency distribution amplifier that can support advanced timing measurements, even at the performance levels of the next generations of atomic frequency standards. Typical timing distribution systems use 5 or 10 MHz signals, but, due to the sensitivity of currently available phase detectors to both temperature and rf amplitude, much better timing performance can be achieved at 100 MHz.

The amplifier provides five outputs for one input and exhibits signal isolation of better than 100 dB. The 1/f noise added by the amplifier stages is extremely low, −163 dBc/Hz at 10 Hz. In addition, a very good match to 50 Ω at both the input and output reduces the voltage-standing-wave ratio, thus minimizing the phase errors that accompany signal reflection. (F. Walls)

■ **Demonstration of a Cryogenic Linear-Ion-Trap Frequency Standard.** John Miller, Dana Berkeland, Jim Bergquist, Wayne Itano, and Dave Wineland of the Time and Frequency Division have developed a cryogenic linear-ion-trap system that can be used to investigate both microwave and optical frequency standards. Presently, the ion used for both standards is $^{199}Hg^{+}$. Trapping of ions eliminates the first-order Doppler shift and laser cooling reduces the second-order Doppler shift to a very low value. Since observation times can be extremely long, linewidths can be very narrow leading to high stability, even for a small number of ions. For this system, fundamental systematic uncertainties are known to nearly one part in 10^{18} on the optical clock transition. Of course, other technical problems might limit performance short of this goal.

In a preliminary test of the microwave standard, the group has demonstrated a frequency stability of 3×10^{-15} at 1,000 s, but further work should improve this result. The dominant systematic effect appears to be caused by a second-order magnetic field shift due to the presence of currents flowing in the trap electrodes at the trap drive frequency. Efforts are currently underway to reduce this shift and establish a calibration procedure to remove its effects. (J. Bergquist)

■ **Crystalline Nonneutral Plasmas.** An atomic frequency standard with good signal-to-noise performance can be constructed using large numbers ($>10^5$) of ions contained in a Penning trap (which achieves trapping using static magnetic and electric fields). However, to date it has been difficult to precisely characterize and control the Doppler shifts associated with the magnetron rotation of such a stored ion plasma. Recently, Joseph Tan, John Bollinger, Pei Huang, Wayne Itano, Brana Jelenkovic, and Dave Wineland of the Division have cooled such a plasma to form a rigid solid, and have developed a method for controlling the rotation rate of this rotating solid. Their methods bring promise for the development of a frequency standard of high accuracy and excellent short-term stability. In addition, they now have strong indications that their plasmas are sufficiently large that they exhibit bulk behavior and could be used to study infinite, strongly coupled one-component plasmas. This is significant because such plasmas are models of dense astrophysical matter and this is the first laboratory system with the potential of generating them in the strongly coupled regime.

The group had previously observed Bragg scattering of laser light from crystallized plasmas, but the rotation of the plasma converted the usual Laue dot pattern to one of concentric rings. This did not allow identification of the lattice type. In recent experiments they have gated (gate time small compared to the rotation period) an imaging system synchronously with the plasma rotation. This has allowed them to recover the Laue dot pattern and helped identify the favored lattice type as body centered cubic (bcc). This is the predicted lattice for an infinite, strongly coupled one-component plasma. The group has also used a "rotating wall" to precisely control the magnetron rotation of the crystalline plasma. The rotating wall is a rotating electric field generated by six electrodes arranged around the equator of the trap. Bragg scattering studies show that the crystalline plasma orientation can be phase locked to the rotating electric field. This allows precise reproduction of the same rotation rate from experiment to experiment, an important step in controlling the time dilation shift due to the plasma rotation. Other conditions that need to be controlled to produce a constant time dilation shift are the number of trapped ions and the strengths of the trapping fields. (J. Bollinger)

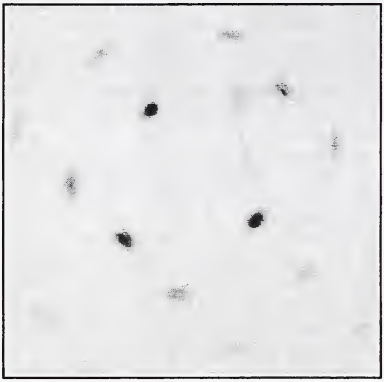


Figure 1. Synchronized Bragg-scattering pattern for a cooled ion plasma. The crystallized plasma rotates at a frequency of 140 kHz, so the imaging system required for these observations must be gated in proper phase with the rotation to obtain this pattern. The rectangular outline near the center is a stop inserted to block the direct laser beam. A regular grid can be drawn through these dots providing evidence that this is a bcc lattice.

■ **Quantum Limits to Measurement and a Quantum Computer.** In earlier experiments, the Ion Storage Group observed what can be called "quantum projection noise." In spectroscopy, this source of noise is caused by the statistical fluctuations in the measured number of absorbers (atomic ions in this case) that are observed to undergo the transition of interest. This was the first observation of this noise source in spectroscopy, and the Group developed and confirmed the theory that describes it.

Having reached this noise floor, John Bollinger, Wayne Itano, and Dave Wineland of the Group then proposed a method for using quantum-mechanically correlated states to reduce the noise below this level. The promise of this method was sufficiently high that a program aimed at realizing the concept was initiated. Their approach involved the development of a linear ion trap capable of storing one-dimensional "strings" of ions along the trap axis. As this work progressed, I. Cirac and P. Zoller from the University of Innsbruck proposed using an identical configuration to produce a quantum computer. The synergism of these two apparently disparate projects, an atomic frequency standard and a quantum computer, is extremely high. In fact, the work that needs to be done to prove the quantum-computer idea will lead quite naturally to the reduced-noise frequency standard, so work on these two projects is now being pursued concurrently.

In the first phase of the computer project, Chris Monroe, Dawn Meekhof, Brian King, Wayne Itano, and Dave Wineland of the Time and Frequency Division have demonstrated the operation of a two-bit "controlled-NOT" quantum logic gate, a fundamental building block of a quantum computer. The two quantum bits are stored in the internal and external degrees of freedom of a single trapped ion which is first laser-cooled to the zero-point energy. This gate is a simplified version of the Cirac/Zoller scheme. Although this minimal system is not useful for computation, it illustrates the basic operations and the problems associated with constructing a large scale quantum computer.

The interest in quantum computation stems from the fact that certain problems can be more efficiently solved on a quantum computer than on a classical computer. In particular, a quantum computer should be able to factorize large numbers very efficiently. This is of interest, because the security of many data encryption schemes relies on the inability of classical computers to factorize large numbers. (D. Wineland)

■ **Observation of a Schrödinger Cat State.** In recent experiments in the Division, Chris Monroe, Dawn Meekhof, Brian King, and Dave Wineland generated a "Schrödinger cat-like" state of matter at the single atom level. In 1935 Schrödinger developed a thought experiment where a cat is placed in a quantum superposition of being dead and alive (correlated with a single radioactive atom that has and has not decayed, respectively). The state of the system is represented by an entangled quantum mechanical wavefunction involving a superposition of two different states. This situation of course defies our sense of reality, where we only observe live or dead cats and we expect that there exist only live and dead cats independent of our observation. This is a classic illustration of the conflict between the existence of quantum superpositions and our real world experience of observation and measurement. Although superposition states such as Schrödinger cat states appear to be absent from the macroscopic world, there is great interest in creating mesoscopic systems (systems having both microscopic and macroscopic features and hence bridging the gap between the quantum and classical worlds). These types of experiments may provide an interesting proving ground in the controversial theory of quantum measurement.

In their experiments, a single laser-cooled and trapped $^9Be^+$ ion is prepared in a quantum superposition of two separate localized positions correlated with different internal states of the ion. This state is prepared by applying several pulses of laser radiation, which "entangle" the internal (electronic) and external (classical-like motional) states of the ion. They verify the superposition by detecting the quantum mechanical interference between the localized wavepackets. Of critical importance in these experiments is the high level of control of the motion of the ion, from the initial laser cooling to the zero-point of energy to the excitation to higher-energy coherent states of motion in the harmonic potential. (C. Monroe)

■ **Quantum States of Motion of a Trapped Atom.** In a generalization of the "Schrödinger cat" work, Dawn Meekhof, Didi Leibfried, Chris Monroe, Brian King, Wayne Itano, and Dave Wineland have recently reported the creation and full determination of several quantum states of motion of a $^9Be^+$ ion bound in a rf (Paul) trap. The states were coherently prepared from an ion that was initially laser cooled to the zero-point of motion. They have created states having both classical and nonclassical character including, thermal, number, coherent, squeezed, and "Schrödinger cat" states. They have then fully reconstructed the motional state using two novel schemes. One determines the density matrix in the number state basis, and the other determines the Wigner function. Their techniques, which are extendable to several simultaneously trapped ions and to other quantum systems, should allow for well-controlled experiments on decoherence and related phenomena on the quantum-classical borderline. (W. Itano)

■ **Improvements in the AT1 Time Scale.** Tom Parker, Jim Gray, and Judah Levine have implemented a number of improvements in the AT1 time scale allowing the Division to more accurately realize UTC in real time. Over the last 17 months, UTC(NIST) has been held within 50 ns of the international UTC maintained by the BIPM. This provides a more accurate time scale for dissemination to high-end users in the United States, and improves the quality of input data to the BIPM on the frequency of the primary-frequency standard, NIST-7.

The key improvements involve the addition of new commercial hydrogen masers and cesium-beam standards to the scale and the development of new reset procedures in the AT1 algorithm. The drift rate of the scale was reduced from 1×10^{-16}/day to 3×10^{-17}/day. The level of random fluctuations of AT1 was also reduced by a factor of 2 to 2×10^{-15} at 100 days. These improvements, shown in Fig. 2, continue a long history of world leadership in time scale operation. Further improvements are expected as two additional masers are added to the scale. (T. Parker)

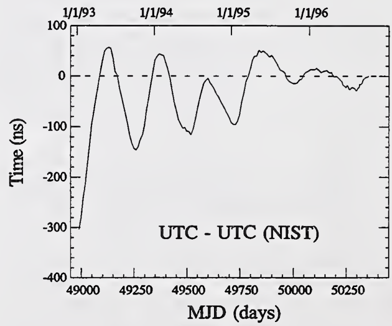


Figure 2. NIST time scale performance. UTC - UTC(NIST) is plotted against the Modified Julian Date (MJD). The time constant for steering to international UTC is apparent in the oscillations. The BIPM feedback of offsets between UTC and UTC(NIST) occurs between 1 and 2 months after data is provided to the BIPM.

■ **Two-Way Satellite Time and Frequency Transfer (TWSTFT).** Christine Hackman, Tom Parker, Franklin Ascarrunz, Steve Jefferts, and Victor Zhang have advanced NIST's TWSTFT capability through four separate projects. In the first, an empirical method was developed for correcting for effects of unevenly spaced data. Two-way time transfer data is typically taken three days per week. Traditional analysis methods, based on evenly spaced data, could not properly account for the noise in the unevenly spaced data, thus limiting knowledge of the measurement uncertainty. In a second project, a complete analysis was made of the time transfer noise between averaging times of 1 s and 100 days. This first-ever analysis indicated a time variance, $\sigma_x(\tau)$, of 100 ps at an averaging time of 100 s and 1 ns with averaging of 1 day clearly establishing the value of the method. In the third project, an investigation was made of systematic variations in the delays through the earth station caused by variations in temperature and microwave power. These measurements provide the basis for correcting for these effects. Finally, improved automation of analysis of the TWSTFT data was implemented saving substantial staff effort in handling of the large data files involved. (T. Parker)

■ **Multi-Channel GPS Receivers for Time Transfer.** Judah Levine of NIST, Al Gifford of the U.S. Naval Observatory, and Tom Bartholomew of The Analytical Sciences Corporation are collaborating on the characterization of time transfer using commercial multi-channel GPS receivers. These receivers make simultaneous observations of eight GPS satellites and support dual-wavelength observations which can be used to estimate the satellite-receiver delay associated with the ionosphere. Variations in ionospheric delay are an important contribution to uncertainty in GPS time transfer. The current method used by NIST involves simultaneous "common-view" observations of the same satellite by different observers, and subsequent processing of many observations to remove common-mode delay errors. This new approach uses a simpler "melting-pot" algorithm for the time transfer process.

The current experiments are being carried out between NIST and the Naval observatory. Making use of the same type of commercial receivers, the group also plans to make measurements between NIST and NASA's Jet Propulsion Laboratory using carrier-phase observations. Such measurements are potentially more accurate, but pose a challenge in resolving the carrier-phase ambiguity, that is, in determining that both sites have identified the same cycle of the carrier and that this identification does not slip during the observation period. (J. Levine)

■ **Telecommunications Synchronization.** Marc Weiss is leading efforts to integrate synchronization concepts developed by the telecommunications industry and by the time-and-frequency community. As part of this effort, NIST has now sponsored five (annual) workshops on synchronization with attendance growing to more than 60 participants per year, mostly from U.S. industry. These workshops grew out of earlier NIST work on synchronization interface standards. The first one was held to familiarize the industry with NIST-developed methods for characterizing synchronization systems. NIST became involved when the industry asked for assistance in developing more useful timing measures. The very rapid success of this venture along with the rapid acceptance of the measures as national and international standards cemented a working relationship that has stimulated the continuation of the workshop into something that more nearly represents a conference on telecommunications synchronization.

In a related project, Steve Jefferts and Marc Weiss are developing a system for two-way time transfer in optical-fiber (SONET) links for application to synchronization of network nodes. The system stability has been shown to be better than 100 ps over a period of 4 hours. This work responds to growing international interest in transmitting timing signals for use within the network. (M. Weiss)

■ **Possible Standard for SONET Time Transmission.** A format for transmitting time through SONET systems has recently been developed. The format involves a single byte of SONET overhead, a part of the SONET frame that does not go through transmission buffers which cause variation in transmission delay. The format is already being used by one company that is developing SONET timing systems for the Department of Defense. It has also been submitted to the International Telecommunications Union (ITU) for consideration as an international standard. The ITU has subsequently submitted the proposal to a study group for more detailed consideration. (J. Levine)

■ **Algorithm for Improving Time Dissemination Through Networks.** In a collaborative effort, Judah Levine along with David Mills of the University of Delaware and Greg Woods of the

National Center for Atmospheric Research have developed an algorithm that is now in use for disseminating time signals through the Internet. The algorithm separates the noise in the calibration channel from the noise in the clock itself and adjusts parameters of the algorithm to optimize performance. The concept used is an application of an earlier patent (granted to NIST) on a "Smart-Clock" concept for maintaining synchronization of a remote clock to a master clock with a minimal number of transmissions. The NIST-patent concept was developed by Dave Allan, Dick Davis, Judah Levine, and Marc Weiss. Their system permits time servers to be located anywhere on the Internet and minimizes variabilities introduced by long network paths. A new version of the algorithm is under development. It will improve characterization of the network delays. (J. Levine)

■ **An Improved Variance for Characterizing Oscillators.** Dave Howe of the Time and Frequency Division has developed an improved variance, closely related to the Allan variance, that provides increased confidence level at long averaging time. This is important because long-term data, requiring long measurement time, is the most costly to obtain. As the method is adopted, manufacturers of oscillators can expect to either reduce measurement time or increase measurement accuracy.

The improvement follows from the simple observation that the procedure for the Allan variance, sometimes called the two-sample variance, measures only frequency variations with an odd symmetry at and near the longest averaging time resulting in a bias. This work constructs a three-sample variance of even symmetry and combines this result with the two-sample variance in order to minimize the bias and thus improve the confidence interval. The process bears a similarity to the method of complex demodulation used in signal processing. The gain in measurement confidence depends on the noise type involved. For white phase-modulation noise, the improvement for the longest averaging time in a data set can be better than an order of magnitude. The improvement is significant, but not quite as dramatic, for higher order noise processes. (D. Howe)

■ **Fundamental Limits on the Frequency Stabilities of Crystal Oscillators.** Fred walls of NIST and John Vig of the U.S. Army Research Laboratory have recently published a review of the instabilities in precision bulk-acoustic-wave (BAW) quartz crystal oscillators. This is the most comprehensive review of this topic in the literature. Their examination of the fundamental limits on achievable frequency stabilities and the degree to which these fundamental limits have been approached provide researchers with a road map for improving the performance of oscillators. Highlights of their study include thermodynamic limits to temperature stability, the limits imposed by noise generated in the electronic sustaining stage, the effects of static and dynamic temperature fluctuations, and the possible role of background ionizing radiation on long-term frequency drift. They conclude their study with a discussion of the ideal resonator and suggest a levitation method for suspending a resonator so as to minimize (or eliminate) the non-ideal effects of resonator suspensions. (F. Walls)

■ **Portable Microwave Phase Noise Standards.** Fred Walls has designed and constructed new portable phase noise standards covering the frequency range from 10 GHz to 40 GHz. These devices generate stable and quantifiable levels of phase noise and are used in round-robin tests of user measurement systems. These were developed with Department of Defense support and three of the standards are being supplied to military calibration laboratories. A fourth system is being retained by NIST for its own calibration services. The device has already been used in several tests of commercial measurement systems and has proven useful in establishing the accuracy of those systems. (F. Walls)

■ **Low Noise RF Devices.** Fred Walls, Eva Ferre-Pikal, and Steve Jefferts of the Division have collaborated in the development of design rules that are proving highly effective in reducing close-to-the-carrier noise in semiconductor amplifiers and related devices. They initially developed the theory describing just how 1/f noise enters these devices and then generated design rules that would minimize the noise. Amplifiers constructed using their methods exhibit 1/f noise that is below thermal noise for all frequencies above a few hertz. By comparison, in conventional amplifiers this crossover occurs somewhere between 100 Hz and 1 kHz. A key component of this research effort was the development of measurement systems for measuring very low levels of both PM and AM noise. In order to transfer this capability to industry, the Division now offers special courses on low noise amplifier design, and several have been presented. Figure 3 shows an example of performance improvement (F. Walls)

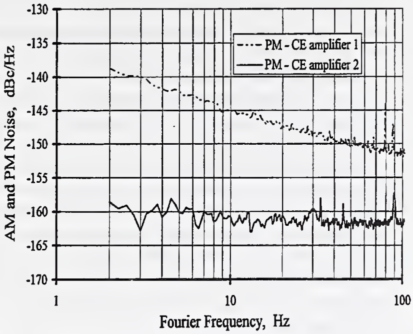


Figure 3. Phase noise as a function of frequency measured from the carrier for a bipolar-junction-transistor amplifier. This figure shows the noise performance of both a conventional state-of-the-art amplifier and the same amplifier after improvements have been made using the techniques described here.

■ **Voltage Noise in Chemical Cells.** Chadwick Boggs and Alan Doak of the University of Colorado, along with Fred Walls of the Division have recently reported measurements of voltage noise on a variety of chemical cells. Chemical cells have often been used in electronics for their low current drift, isolation of a particular circuit from other circuits, and low voltage noise. While it is clear that voltage noise on these cells is small, actual values for the voltage noise have not been reported, so there has been little evidence suggesting that one type of cell might be better than another.

This work was made possible by the development of a cross-correlation measurement system capable of measuring voltage noise below −200 dBV/Hz. The method involves two parallel measurement channels. Because the measurement noises in these two channels are completely independent, a cross-correlation of the outputs of the two channels effectively rejects the measurement noise while recovering the noise on the device under test.

Nickel-cadmium cells exhibited the lowest noise of all cells tested over the frequency range from 1 Hz to 60 kHz. An AA-size nickel-cadmium cell showed a noise of −205 dBV/Hz at 10 kHz. This noise level is consistent with the Johnson noise produced by the 0.2 Ω internal resistance of the cell. The study involved nickel-cadmium, alkaline, lithium, and mercury cells. A general conclusion of the study was that the dominant broadband noise process in cells is the Johnson noise arising from the internal resistance. This clearly indicates that larger capacity batteries with lower internal resistance should produce lower voltage noise. The voltage noise was found to be independent of bias current suggesting that shot noise is not significant. The results of this study should provide guidance in electronics applications demanding the lowest possible levels of voltage noise. (F. Walls)

■ **Computer Time Services Expand.** The Time and Frequency Division operates two time services, one through the telephone system and one through the Internet. Both systems have recently been expanded to accommodate increased usage. The Automated Computer Time Service (ACTS), which provides digital signals through the telephone system has been expanded to fourteen telephone lines, twelve for use with high-speed modems and two for use at low speed where the modem delay is more predictable. Since this system provides a mechanism for measuring telephone transmission delay, the latter option provides lower time uncertainty (1-3 ms). ACTS now handles more than 10,000 calls per day and usage is still growing.

The NIST Network Time Service (NNTS), introduced less than three years ago, has grown even more dramatically. Three servers are now handling nearly 200,000 calls per day and three new servers will be added this year bringing the total to six. Two will be in Boulder, two in Gaithersburg and two on the west coast. This will allow users in the U.S. to select a server in reasonable proximity, thus minimizing transmission delay. (J. Levine)

■ **Windows Software for Net and Telephone Time Services.** Judah Levine of the Division has recently developed two windows programs, one for use with the Automated Computer Time Service (ACTS) and one for use with the NIST Network Time Service (NNTS). These user friendly programs will be available for distribution upon completion of beta testing. The software, including all source code is made available so that commercial software writers can incorporate it into systems with broader application. (J. Levine)

Upgraded Time Broadcasts from WWVB. The Services Group of the Division has embarked on a major renovation and enhancement of the time broadcasts from radio station WWVB in Fort Collins, Colorado. These broadcasts are attractive for a number of applications because receivers and their antennas can be particularly simple, small, and inexpensive, and because signal reception within buildings is feasible. However, the presently available signal strength has been marginal, particularly in areas along the U.S. east coast. One of the key objectives of this effort is to increase the signal strength by at least 6 dB. This will provide U.S. industry options for new products serving both high-end timing applications and consumer needs.

A key roadblock to this project has been the very high cost of new transmitters. This difficulty was overcome when the Navy agreed to provide NIST with three spare high-power transmitters which they had in storage. Purchased new, these transmitters would have cost NIST more than $1M. Installation of the transmitters requires substantial engineering modifications at the site. These include new transmission lines to antennas, new impedance matching networks, and modified interfacing to the transmitters. The present plan (barring major changes in available funding) is to complete installation and modifications by September of 1997. (D. Hanson)

Diode-Laser Wavelength Standard for Absolute Distance Measurement. A major milestone has been reached in a collaboration on wavelength standards between Divisions of the Physics Laboratory and the Manufacturing Engineering Laboratory. Swept-frequency lasers, developed jointly by staff of the Time and Frequency Division in Boulder and the Precision Engineering Division in Gaithersburg, are now being used in studies on improved absolute-distance measurement being conducted by the Precision Engineering Division. Both Divisions contributed to the design and both will characterize the laser for this application. The Precision Engineering Division has responsibility for length metrology, while the Time and Frequency Division has responsibility for providing access to the second, in part via laser wavelength reference standards.

The laser system for this project was developed by Michelle Stephens and Leo Hollberg of the Division, who converted a commercial diode laser into a tunable laser with the desired sweep characteristics. The laser system is now being evaluated by Lowell Howard and Jack Stone of the Manufacturing Engineering Laboratory. By comparison with commercial, tunable, visible diode lasers, the one developed at NIST can sweep either 100 times farther than those with comparable rate or 100 times faster than those with a comparable range. With its unique ability to continuously and rapidly sweep its central wavelength near 680 nm over a range of 2 nm, the laser will allow development of an absolute-distance interferometry system which can overcome the limitations of present displacement interferometry systems which require an uninterrupted beam. With the new interferometer system, absolute distance between the reflectors of the interferometer can be measured directly many times per second rather than requiring the position of one reflector to be physically translated over the distance to be measured. (M. Stephens, L. Howard)

IUPAC Sets Wavenumber Standards for the Infrared. The International Union of Pure and Applied Chemistry (IUPAC) Working Group on "Unified Wavenumber Standards" has recently issued a set of recommendations for high resolution wavenumber standards for the infrared region of the spectrum. The document provides wavenumber standards for calibration of high-resolution infrared spectrometers where measurements have traditionally been more precise than accurate. The most accurate standards are derived from direct frequency-measured, saturated infrared absorptions. These are converted to wavenumber using the 1983 redefinition of the meter in terms of the second. The spectral lines cited by the Group cover the range from about 4 cm^{-1} to about 7,000 cm^{-1}. The standards will allow much better comparison of measurements made at different laboratories.

NIST representation in this report included Joe Wells and Ken Evenson of the Division and Art Maki of the University of Washington (formerly with the former NIST Molecular Physics Division). A very large share of the measurements cited in the recommendations were made at NIST. Many of these recommendations are taken from NIST Special Publication 821, "Wavenumber Calibration Tables from Heterodyne Frequency Measurements" by A.G. Maki and J.S. Wells. (K. Evenson)

Optical Frequency Division by a Factor of Three. Joe Wells and Leo Hollberg of the Division, along with Olivier Pfister of the University of Colorado, Manfred Mürtz of the University of Bonn, and James Murray of the University of

Arizona have developed a new scheme for coherently connecting optical frequencies in a 3:1 ratio. They have demonstrated the method by locking the outputs of a Nd:YAG laser at 1064 nm with a CO overtone laser at 3192 nm. This is a significant step in the development of simpler frequency synthesis chains, since in combination with divide by 2 devices, greater flexibility in design is achieved. There are a number of examples where division by 3 is advantageous. For example, at NIST the very high-Q ultraviolet transition at 282 nm in Hg^+ will be excited with the twice-frequency-doubled ND:FAP laser at 1126 nm. When divided by a factor of 3, this yields a wavelength of 3378 nm, which is close to the very important methane reference.

This work is part of a larger Division effort to develop new methods and components that can contribute to the simplification of optical frequency measurement and the construction of much simpler frequency synthesis chains. The long term objective is a robust and simple chain linking the cesium frequency standard to the optical region. (L. Hollberg)

■ **Calcium Optical Molasses.** Michelle Stephens, Chris Oates, and Leo Hollberg have cooled and trapped calcium using frequency-doubled diode lasers. They had previously done high-resolution spectroscopic studies of the 657 nm line in calcium, but this earlier work was limited by the Ramsey-method, interaction-time linewidth of a few kHz. The cooled and trapped atoms should now allow them to observe the intrinsic linewidth of 400 Hz. Furthermore, the use of diode lasers at 423 nm for cooling and trapping of the atoms and for interrogation of the 657 nm transition results in a relatively small system that could be made transportable for comparisons. This is a particularly attractive optical frequency standard because the first-order Doppler shift is removed by the trapping, the second-order shift is substantially reduced by cooling, and the 657 nm line is only slightly sensitive (in second order) to electric and magnetic fields.

The system that generates the 423 nm radiation is particularly efficient. Infrared diode-laser radiation is doubled to 423 nm using a potassium niobate crystal. The excellent matching of this laser and crystal is such that the blue output is down in power from the IR laser by only a factor of 3. More power is now available at the 423 nm wavelength than at 657 nm. (M. Stephens)

■ **Optical-Delay-Line Oscillator.** John Kitching, Leo Hollberg, and Fred Walls of the Division have recently demonstrated a 1 GHz optical-delay-line oscillator driven by a diode laser. This is not the first such oscillator, but this one differs from previous devices in its use of a directly modulated diode laser rather than a fixed-frequency laser and an electro-optic modulator. Light from the diode laser travels down the fiber to strike a detector where it is converted to an electronic signal that is filtered, amplified, and then applied back to the injection current of the diode laser. When the loop gain exceeds unity, the system oscillates at a frequency consistent with phase shift closure (a multiple of 2π) around the loop. The very low phase noise of the system derives from the long delay time and very low loss provided by the optical fiber.

The study concludes that optical-delay-line oscillators might be good alternatives to crystal and dielectric-resonator oscillators if the oscillation frequency can be increased beyond 10 GHz. At 1 GHz they observe a single-sideband phase noise spectrum decreasing as roughly $1/f^2$ attaining a value of -138 dB below the carrier in a 1 Hz bandwidth at 20 kHz offset. These oscillators are in their infancy and there is much room for improvement. For example, the fiber-generated noise can be reduced by running at 1.3 μm rather than 850 nm, since fibers at 1.3 μm exhibit much lower loss and scattering. Extending this work to higher frequency will require high power lasers with large modulation bandwidths and high-speed photodiodes that can handle tens of mW of optical power. (L. Hollberg)

■ **30 THz Mixing Experiments Using High-T_c Josephson Junctions.** Eric Grossman, Leila Vale, and David Rudman of the Electromagnetic Technology Division of EEEL along with Ken Evenson and Lyndon Zink of the Time and Frequency Division recently published a paper describing their experiments on high-frequency mixing in high-T_c Josephson junctions. They directly observed second-order difference frequencies from 10 MHz to 12.8 GHz between two CO_2 laser lines near 30 THz. Applying a third microwave signal to the junction, they observed laser difference frequencies up to 27 GHz. This is the first observation of Josephson mixing at CO_2 frequencies in high-T_c junctions. The hope is that these devices can be further developed to provide simpler means for synthesizing and measuring optical signals at arbitrary frequencies.

The thin-film $YBa_2Cu_3O_{7-\delta}$ superconductor-normal-superconductor junctions were fabricated in EEEL's Boulder facilities. The dc-bias dependence of the difference signal, as well as other evidence, suggests two distinct mixing mechanisms: hot-electron mixing in the junction banks at high dc bias, and bolometric Josephson mixing at low dc bias. The latter mixing mechanism is superior for third and higher-order mixing products. (K. Evenson)

■ **Observation of Laser Oscillation Without Population Inversion.** In a recent collaboration with scientists from Texas A&M University and Russia's Lebedev Institute of Physics, Leo Hollberg and Hugh Robinson of the Time and Frequency Division have demonstrated laser oscillation without population inversion (LWI). Collaborators at Texas A&M included A.S. Zibrov, M.D. Lukin, D.E. Nikonov, and M.O. Scully. V.L. Velichansky of the Lebedev Institute also participated in the work. The experiments, carried out at NIST, followed the surprising theoretical prediction that, in a V-type configuration of energy levels, atomic coherence can result in gain without population inversion. A strong driving field on one transition has a significant effect on a second transition that shares the same ground state as the driven transition. Related coherence effects had already been observed, but this was the first demonstration of actual lasing without inversion.

The experiments were done in a rubidium cell using only 10 mW of drive power from diode lasers. Measurements showed that the observed oscillation occurred without population inversion, and that it was the presence of the coherent drive-laser radiation that produced the conditions necessary for oscillation. Earlier, the group reported cw amplification without inversion in the same system, but more efficient containment of photons was needed before the system would oscillate.

The work has possible practical implications. In particular it suggests the possibility that short wavelength lasers (in the ultraviolet region and beyond) might be feasible. While the work described here involved laser oscillation at a wavelength not too far from the wavelength of the drive laser, there is now the clear possibility that the same approach could be used to produce laser oscillation at much shorter wavelength, far removed from the wavelength of the drive laser. Experiments to test this possibility are in progress. (L. Hollberg)

■ **Improved CO_2 Laser.** Ken Evenson, using a new grating produced by a local Boulder optical manufacturer, has developed a CO_2 laser that oscillates on more than 275 lines with a maximum power output of 30 W. Most CO_2 lasers will oscillate on only about 80 lines. The laser uses a grating to couple power out of the laser in zero order. The new laser, when locked to sub-Doppler lines in CO_2, is an excellent infrared frequency and wavelength standard. The laser is also a good source of radiation for pumping far-infrared lasers.

Three years ago, Evenson developed a new ribbed laser tube. The ribs act as irises and greatly increase the grating resolution of the laser cavity. This provided a big improvement in performance, because the ribbed structure reduces or eliminates modes associated with radiation bouncing off the tube walls. The latest improvement is a direct result of the improved grating which couples out 3% of the power over the region from 9 to 11.5 μm. The new grating, with 150 lines/mm, was developed by a local optical manufacturer in direct response to NIST requirements and was tested and proven at NIST. Figure 4 below shows the laser output as the grating angle is scanned to select the various laser lines. The laser has a mirror separation of 2.16 m and a diameter of 18 mm. (K. Evenson)

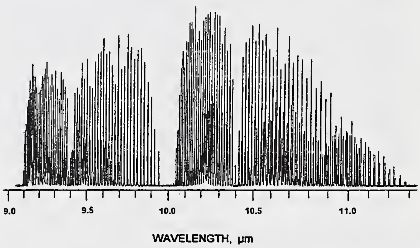


Figure 4. Output of the new CO_2 laser as a function of wavelength. This plot was made by scanning the grating angle to select the various laser lines.

■ **High Resolution Spectroscopy Supporting Atmospheric Chemistry Studies.** Diode-laser systems developed for use with optical and microwave frequency standards are also proving useful for spectroscopic detection of molecular species important in the chemistry of the upper atmosphere. With NOAA's atmospheric scientists sharing adjacent facilities, a natural collaboration has developed on the application of these lasers to their measurement problems. A notable recent success is a collaboration between NOAA scientists and Rich Fox of NIST on the detection of NO_3. This radical plays a key role in nighttime atmospheric chemistry, interacting for example with molecules involving chlorine. NO_3 dissociates in sunlight. Their recently reported measurements quantify NO_3 reactions with other key species providing input to atmospheric models.

NO_3 has a strong electronic absorption band at 662 nm that can be reached with commercial red diode lasers. In these experiments a solitary diode laser is used to detect the time-dependent concentration of NO_3 in a cell containing gases of atmospheric interest. Good detection sensitivity is achieved with direct absorption measurements. The interaction path is increased using reflected multiple passage of the laser beam through the cell. In addition, they have frequency doubled the light from infrared diode lasers to produce precisely tunable blue light that can be used to detect other important atomic and molecular resonances. For example, laser light at 425 nm, generated by this technique, has been applied to the high-sensitivity detection of the IO molecule. Both NO_3 and IO play important roles in determining the concentration of ozone in the atmosphere. (R. Fox)

■ **Detection of Methane in Air.** In a collaborative program, Frank Tittel of Rice University, Ed Dlugokencky of NOAA, and Steve Waltman of the Division have developed a laser-spectroscopy-based system that can determine methane concentration in air to 1×10^{-9}. The approach is dramatically simpler and the system much more portable than the chemical processing and gas chromatography methods currently used. Furthermore, the new spectroscopic method is a non-destructive, real-time measurement as opposed to the laborious and destructive analytical measurements now employed. Methane concentrations in the atmosphere are believed to have a substantial impact on the greenhouse effect, so simpler methods for long-term monitoring are especially important. The normal concentration of methane in air is about 2×10^{-6}, and measurements over the last decade indicate that its average concentration has been increasing at a rate of about 1×10^{-8} per year for reasons that are not yet well understood.

The spectroscopic system used for this detection operates at a laser wavelength of approximately 3.3 μm on a methane line that is well separated from a weak water line, so the measurements are not disturbed by varying water concentration. The 3.3 μm radiation is generated by difference mixing the outputs of a diode-pumped YAG laser at 1.06 μm and a diode laser operating at 805 nm. The system could easily be designed to be transportable. It could also be installed at fixed locations to provide continuous monitoring. An additional benefit of spectroscopic monitoring is that the system can be tuned to be sensitive only to methane containing ^{13}C rather than the usual ^{12}C atoms. Thus, it should be possible to use this non-radioactive species in a method similar to radioactive labeling to monitor the movement of ^{13}C-labeled methane through any type of system. (S. Waltman)

■ **New Observations Using LMR Spectroscopy.** Ken Evenson of the Time and Frequency Division, along with John Brown of Oxford University and Helga Koersgen of the University of Bonn, have recently made several new observations using laser magnetic resonance (LMR) spectroscopy. They have made the first direct observation of the far-infrared, $J = 3/2 \rightarrow J = 1/2$ transition of the Fe^+ ion at 86.7 μm. Their measurement uncertainty for this transition is about 100 times smaller than that of indirect observations made using differences of optical-wavelength measurements. They have also used LMR to observe the spectrum of the FeD_2 molecule near 6.9 THz (43 μm). This required modification of their spectrometer so that it could operate at these high frequencies. To date, these are the highest frequency FIR LMR observations and the first FIR observations of a vibrational bending spectrum made using LMR spectroscopy.

Iron is presumed to be an abundant interstellar species, and its spectrum is prominent in solar observations. However, it has never been observed in interstellar space. These new observations provide radio astronomers with reference spectra for searches for these particular iron species. The development of a capability for higher frequency observations opens up significant new opportunities for measurements of importance not only to radio astronomy, but also to upper-atmospheric research. The modified spectrometer now covers frequencies to the upper limit used by radio astronomers. This expanded range covers fine-structure transitions in a number of atoms and molecules allowing for the exacting laboratory frequency measurements needed to support searches for these atoms in space. Furthermore, ClO, an important molecule in the upper atmosphere, has a fine structure transition at 8.2 THz. This transition might provide the best means for determining the abundance of this species in the upper atmosphere, contributing information on atmospheric (ozone) chemistry. (K. Evenson)

FUTURE DIRECTIONS

During the next few years the Division will place special emphasis on four topics. These are:

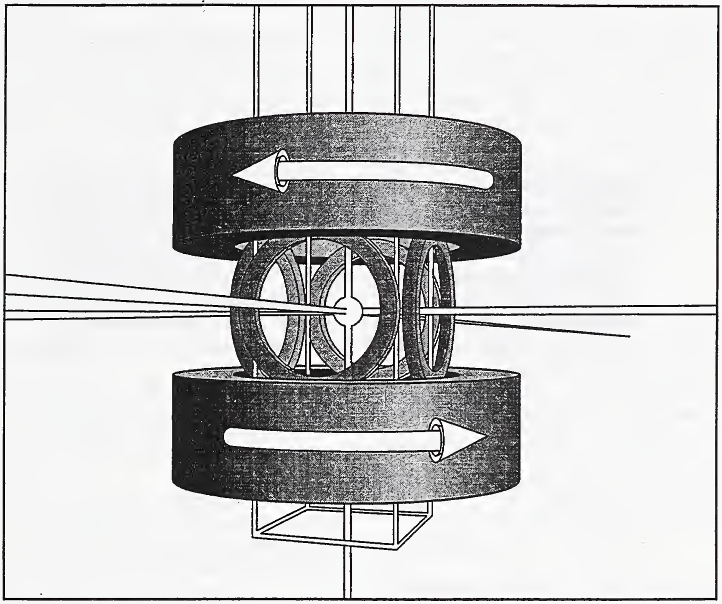
- **Development of New Primary Frequency Standards.** With the wide range of new concepts for controlling states and motions of atoms, the opportunity for dramatic advances is enormous.

- **Improvement of Performance and Quality Control of Services.** Improvements will be made in WWVB, the telephone time service and the Internet time service. Conforming with ISO 9000 trends, the Division will further document and improve quality control of all services.

- **Improvement of International Time Coordination.** To support increasing accuracy of primary frequency standards, improvements will be made in common-view and two-way time transfer.

- **Development of a Frequency Synthesis Chain.** Simpler methods for optical frequency synthesis will be developed to support length metrology and optical, primary-frequency standards. □

QUANTUM PHYSICS DIVISION



Overleaf

Magneto-optical trap. Schematic of the apparatus used to cool atoms to almost absolute zero, resulting in the world's first demonstration of Bose-Einstein Condensation. Six laser beams intersect in a glass cell placed between magnetic coils, creating a magneto-optical trap (MOT). The glass cell hangs from a chamber (not shown) containing a vacuum pump and rubidium source. Also not shown are coils for injecting the rf magnetic field for evaporation and the additional laser beams for imaging and optically pumping the trapped atom sample.

QUANTUM PHYSICS DIVISION

MISSION

A recently approved mission statement reflects the interdisciplinary nature of the Division by replacing the previous "group" structure with several thrusts in which any or all of the members participate:

- Fundamental and Precision Measurements
- Optical and Nonlinear Optical Physics
- Materials Interactions and Characterization.

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

Through the Quantum Physics Division, NIST participates in JILA, a cooperative enterprise between NIST and the University of Colorado (CU) located on the University campus in Boulder, Colorado.

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 materials processing;
- researching new techniques to produce and measure fundamental properties of matter, such as Bose-Einstein condensation.

Seven Division senior scientists and one NIST scientist from the Time and Frequency Division (all JILA Fellows) share facilities and responsibility for the success of JILA with the 14 JILA Fellows who hold University of Colorado appointments. The NIST scientists are Adjoint Professors or Lecturers at the University, six in Physics and two in Chemistry. At the present time, 62 graduate students and postdocs are supervised by NIST scientists, and approximately 22 JILA staff are directly associated with NIST activities.

The unique Visiting Fellows program brings, each year, some 6 to 10 internationally distinguished scientists to spend up to twelve months at JILA collaborating with resident scientists. Their presence is an important factor in maintaining the atmosphere of change and scientific excellence at JILA. The Visiting Fellows Program has been steered to attract additional visitors from industry, specifically allocating some of the funds to be used for shorter term visits by industry representatives.

CURRENT DIRECTIONS

- **Bose-Einstein Condensation.** Work continues in this field pioneered by JILA scientists. Now that the condensate can be formed, the current research focuses on discovering its characteristics, which consititutes "new physics."

- **Improved Resolution in NSOM.** The atomic scale sharpness of nanocolumns is used to enhance the electric field of a laser in the field of an STM probe tip, and thereby to seek dramatic improvement in spatial resolution over conventional NSOM fiber optic methods.

- **Detection of Flaws in Films.** STM images only a few nanometers wide have been recorded of particles in films for solar panels and large flat-panel displays. This type of flaw (included particles) can reduce the efficiency of certain light-sensitive films.

TECHNICAL HIGHLIGHTS

- **Characterizing the Bose-Einstein Condensate.** The world's first observation of Bose-Einstein condensation (BEC) in a dilute gas was made at JILA in June of 1995. Since then the JILA BEC group has performed a variety of experiments with the goal of characterizing the basic properties of this novel quantum fluid. One study produced a relatively precise measurement of the critical temperature and a preliminary measure of the specific heat near the transition. It turned out that the basic value predicted in 1925 was correct. A second round of observations determined the frequencies of the lowest-order standing-wave acoustic modes in the sample. These phonon-like excitations are providing an important handle on the fluid properties of the condensate. The rate at which the excitations damp out, for example, is a measure of the viscosity of the condensate fluid. Most recently, it has been discovered that as the temperature of the sample is decreased further and further below the transition temperature, the excitations take longer and longer to damp out, indicating that the viscosity of the sample gets very small at low temperatures. (Cornell [Wieman, CU], Jin)

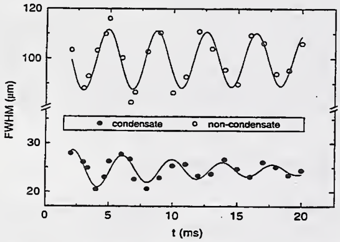


Figure 1. Widths of each component, condensate and non-condensate, of the freely oscillating cloud are fit by an exponentially damped sine wave. For each pair of points (condensate and non-condensate widths) a fresh cloud of atoms is cooled, excited, and allowed to evolve a time t before a single destructive measurement.

■ **Mechanical measurements.** The expanding need is being addressed for accurate and less costly methods of measurement in the production of, for example, microprocessors, which require the accurate positioning of up to 25 successive patterning masks over a period of about two weeks. Optical interferometry with the ubiquitous HeNe laser is commonly used to sense and control for any minor flexures, but the limited *accuracy* of this measurement is a growing problem. The heat of the HeNe laser can distort the measuring apparatus by thermal expansion, and the speed of light which scales frequency into length depends importantly upon the ambient temperature, pressure, moisture and other compositional variations of the ambient air.

A small and low-cost method has been developed for reading the actual index of refraction *in situ*, based on video camera capture and computer processing of the interference rings of a simple stable interferometer designed with an air flow channel between its mirrors. This system has been patented. In future technology, it is clear that a semiconductor diode laser will be the laser of choice, due to its long life, higher light output and vastly lower heat generation. Frequency-comparison of a 633 nm semiconductor diode laser with the HeNe laser standard based on iodine molecular absorption shows very attractive stability: drift below 2×10^{-8} in one week in the very first trials. Thus when the cavity is exposed to ambient air, there is confidence that a stabilized wavelength source is achieved for precision interferometry whose *wavelength* is constant in the laboratory. Industrial design of this system can be packaged in the volume of a box of the current 3.5 inch minifloppy disks. One can foresee wide application of this stabilized laser, in either its constant wavelength or constant frequency modes in many practical tasks in engineering and science. (Hall)

■ **Optical Frequency Measurement Techniques.** Preliminary results have been obtained on the use of a strongly-driven electro-optic modulator situated within a low-loss and resonant cavity. World-wide interest in these devices is exploding for their use as an "optical comb generator." Better parameters have been achieved than have been so far reported from other laboratories. A novel frequency-selective cavity mirror allows effective in-coupling of the monochromatic light to be modulated, and out-coupling of the selected frequency-shifted "comb" component. Observations of useful sidebands shifted by > 1.5 THz have been made. (Hall)

■ **Super Spring.** Work continues on developing and understanding the limitations of simple spring systems designed to achieve long periods with compact-structured springs. This development should have enormous practical consequences. The basic pretensioned spring system has been modified through the addition of spring-constant-canceling auxiliary spring elements to overcome the slow scaling improvements beyond that initially achieved from extreme pre-stressing. The improvement is not rapid enough to justify the required increase in the number of elements. Using the auxiliary springs, one can in principle get an infinite period with just a single element – 10 s is the

JILA record to date. Research is focusing on ways to eliminate or at least greatly reduce the complications of internal modes. (Faller)

■ **Measurement of Newtonian Gravitational Constant.** An FG5 absolute gravimeter is being used, together with a moveable 1200 kg tungsten mass surrounding the dropping chamber, to measure big G, the Newtonian constant of gravitation. This work, with a large cast of collaborators from the National Geological Society, Micro-g solutions, and JILA is motivated by the present nearly 1% discrepancy between the recent Physikalisch Techniche Budesanstalt (PTB) measurement and the "accepted" value. The fact that the PTB measurement appears to have been competently and thoughtfully done makes the discrepancy even more intriguing. A proof-of-concept experiment was carried out using an existing 100 kg bronze mass and the data analysis is nearing completion. It appears that a preliminary result of 1% or better will be obtained and that optimization of the mass geometry together with an increase of its mass should yield an order of magnitude better result. (Faller)

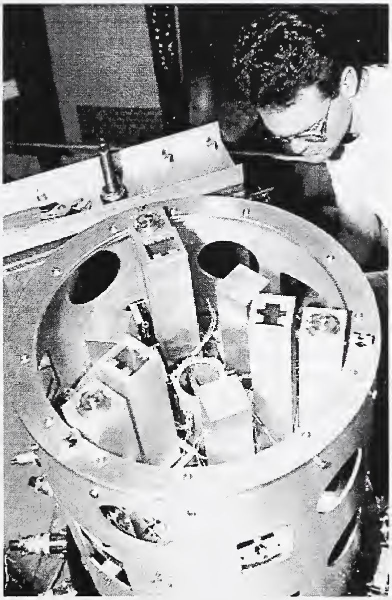


Figure 2. Graduate student Sam Richman with the isolation chamber.

■ **Active Low-Frequency Isolation System.** Excellent progress has been made by Division researchers on this isolation system planned for use on the Laser Interferometer Gravitational Observatory (LIGO). The now operating preliminary single stage provides more isolation at 1 Hz than any other research or commercial isolation system. Preliminary tests with the single stage operating in all 6 degrees of freedom and the next stage with only the three vertical loops locked have also been carried out and the initial results are very encouraging. In addition to the LIGO (Caltech and MIT) group there is a possibility of working with the British-German GEO-600 gravity wave detector group. Since the GEO-600 involves smaller sized mirrors, a cooperative venture could provide an excellent proof of concept test for the larger versions of the JILA isolators that will be required for LIGO. (Faller [Bender, CU])

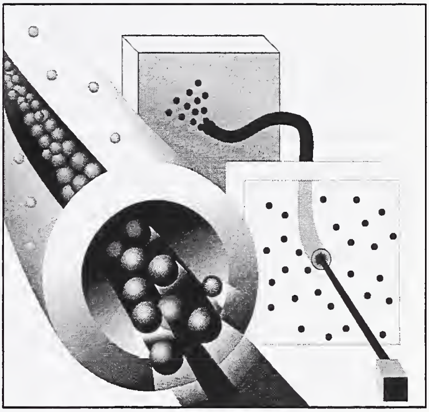


Figure 3.

■ **Atom Guiding in Hollow Fibers.** JILA researchers have been using the force that light exerts on atoms to guide atoms through hollow glass fibers. Glass fibers can guide light, and light can guide atoms, preventing them from touching the inside of the glass. The result is a flexible atom guide, a useful building block for many atom optics experiments, including atom interferometry. In recent work, atoms have been guided using the evanescent light field from laser light confined in the annular region surrounding the hollow core. Researchers have been successful in demonstrating the cooling of the atoms inside the fiber. Current research directions include loading atoms with a laser cooled, intense atomic beam and guiding through ever smaller diameter fibers. (Cornell [Anderson and Wieman, CU])

■ **Tests of QED.** A new and potentially important test of Quantum Electrodynamics (QED) has become of interest due to the abrupt availability of powerful dipole magnets originally developed for the Superconductor Super Collider (SSC). QED theory predicts that in a "light-by-light" scattering process, even an ideal vacuum becomes slightly birefringent due to a powerful transverse magnetic field. For the experiment at Fermilab, the readout methods are based on use of a Direct Digital Synthesis to produce a test frequency of adequately high resolution and low noise and, of course, on the use of "super mirrors" and a long interaction region (50 m). Some new modulation methods that optimally isolate the desired birefringence signal from the influence of residual laser frequency noise will also be used. In view of the importance of the subject and the general utility of new laser locking techniques, a research phase is now underway, mainly at JILA, to prove the new techniques and identify limiting factors. (Hall)

■ **Kinetic-Energy-Enhanced Etching of Silicon.** Potentially damaging effects of the dry process plasma etching steps will become a critical issue when gate oxides of semiconductor devices shrink to 5 nm thicknesses. Thus there is considerable recent interest in the possibility of supplying energy for the etching process in the form of neutral-species kinetic energy. New work in this area by the Division involves the development of a more general source of kinetic-energy-enhanced neutrals by extraction and charge neutralization of ions from a plasma source. The kinetic energy distributions of ion and neutral species emanating from those plasmas containing rare gases, chlorine, or nitrogen have now been characterized. Laser single photon ionization has also been used to measure the SiCl and $SiCl_2$ products of thermal chlorine etching of Si(100). (Leone)

■ **Time-Resolved Near Field Optical Microscopy (NSOM).** Ultraminiature devices, such as recording heads for hard disk storage based on the magnetoresistive effect, already exceed the limits of measurement capability required to analyze the size and quality of the layered structures. When the devices fail or are fabricated improperly, there is no way to determine what went wrong in the process. New kinds of measurement capabilities are eventually needed that have both element-specific sensitivity and 1 to 10 nm resolution. Such measurement capabilities will ultimately also be invaluable to the broader microelectronics and photonics industry.

In a competence initiative through NIST, the Division is investigating the application of near field optical microscopy for both time-resolved and spectral characterizations of materials and molecules. NSOM images have been obtained in transmission and fluorescence using conventional transparent fiber optic probes with spatial resolutions of 100 nm or less. Aggregates of dye molecules have been imaged successfully with the home-built arrangement. A project has been initiated to study hybrid NSOM assisted by scanning tunneling methods. The basic idea is to use the atomic scale sharpness of nanocolumns to enhance the electric field of a laser in the near field of an STM probe tip, and thereby achieve dramatic improvement in spatial resolution over conventional NSOM fiber optic methods. In future experiments, two time-delayed pulses from a ps pulsed laser will be used to prepare and probe optically induced changes in transmission, which will introduce time-contrast mechanisms into the images. (Leone, Cornell, Gallagher, Nesbitt)

■ **STM Images Reveal Flaw Formation in Films for Solar Panels and Large Flat-Panel Displays.** Images of particles only a few nanometers wide, which can reduce the efficiency of certain light-sensitive films, are observed in the plasma processing of solar panel films. Large area films are used in making solar energy panels and large flat-panel displays. The efficiency of the film in converting light into electrical current is best for very thin homogeneous films about 500 nm thick.

A custom built system for both growing thin films and examining them with an ultra-sensitive scanning tunneling microscope is used. The apparatus can grow amorphous (noncrystalline) films of silicon and hydrogen atoms with plasma-enhanced chemical vapor deposition (PECVD). Images of the film are taken at various stages throughout the growth process. The images show particles 3 to 5 nm in size, which form in the vapor and bond to the film surface during growth. As a new layer of silicon and hydrogen atoms deposits on the surface, these clumps cause voids within the film.

Many people have studied the production of larger particles during PECVD, but these particles are suspended in the plasma and do not reach the growing film. No one appears to have realized that small particles can reach the growing film. If these particles can be prevented from forming or reaching the surface, it should be possible to improve the films' ability to convert light into electrical current. New work will develop a laser-scattering system to detect the silicon/hydrogen clumps as they are forming in the plasma. Laser scattering detects larger particles, but provides a method for real-time monitoring of particulate behavior in the plasma. (Gallagher)

■ **STM Controlled Aluminum Deposition.** The scanning tunneling microscope (STM) can be used to measure surface features with atomic resolution and has the potential to produce atomic scale objects. Silicon semiconductor devices generally use aluminum contacts, so it is highly desirable to learn how to "write" nanometer scale aluminum features on silicon. The Division has made such nanoscale aluminum deposits onto silicon by pinning the aluminum from tri-methyl-aluminum (TMA) vapor with the electron beam from the STM. Detailed studies have revealed the various physical and chemical steps involved, and the electrical characteristics of these nanometer size contacts. (Gallagher)

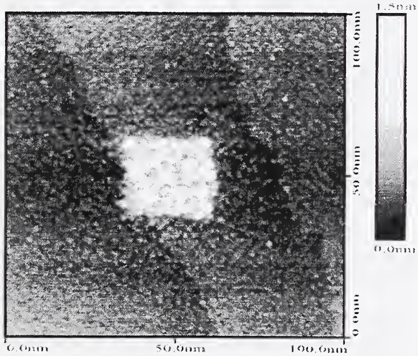


Figure 4. Pad deposited on x-Si(001) at -10 V and 8.8 L of TMA.

■ **Quantum State Resolved Sublimation Dynamics of Thin Molecular Films.** The dynamics of how molecules collide with, stick to, and bounce off a surface is of considerable importance in molecular beam epitaxy applications. By virtue of microscopic reversibility, such dynamics can also be probed by monitoring the nascent quantum state distributions of molecules *subliming* from thin films. Under sufficiently low vapor pressure conditions, such quantum state resolved studies can be performed by high resolution diode laser direct absorption experiments, 5 mm above a temperature-controlled surface. Such direct absorption methods have been developed by the Division to study CO_2 sublimation dynamics from thin CO_2 films, using frequency-swept diode laser methods to obtain 1 monolayer/s detection sensitivities. The single-mode diode laser provides resolution of all vibration/rotation states in CO_2, as well as a selective probe of higher clusters ($n=2,3$) in the subliming flux. From 90 K to 120 K, however, all $J<40$ sublimation populations are indistinguishable (± 5 K) from thermal prediction at the surface temperature, indicating no quantum state dependence to the reverse gas-surface sticking event. Translational velocity distributions are obtained from high resolution analysis of the 4.3 mm Doppler profiles, yielding a speed distribution also consistent with the surface temperature. Since absolute fluxes can be readily measured by the direct absorption method, this data can be converted into an absolute sticking coefficient of 1.0 ± 0.1. Modeling of the surface dynamics with CO_2-CO_2 pair potentials predicts a surprisingly "soft" landing for the impinging CO_2, which is most probably responsible for such efficient and quantum state independent sticking behavior. (Nesbitt)

■ **Electron Collisions.** The merged electron-ion beams energy loss (MEIBEL) technique developed at JILA has been used to measure the cross sections for electron-impact excitation of multiply charged ions to spin-forbidden states. Most recently, the process $e + Ar^{6+}(3s^2\ {}^1S) \rightarrow e + (3s3p\ {}^3P^0)$ was studied using the technique. As expected, resonances dominated the cross section in the threshold region. Comparison with theory shows that there is significant resonance interference. In fact, the interference is so sensitive to the exact location (energy-wise) of the resonances that present computational techniques may not be capable of giving accurate enough energy values to predict the resonance interference adequately.

A collaboration between JILA and Swedish and German scientists has resulted in measurements of the effects of ambient electric fields on dielectronic recombination cross sections for Si^{11+}. It was shown in JILA experiments in the 1980's on Mg^+ that dielectronic recombination cross sections could be increased by large factors through state mixing by external fields. However, there have been no further definitive measurements despite many efforts by others. The recent work on Si^{11+} on the heavy ion storage ring (CRYRING) in Stockholm has yielded very clear effects that will complement the earlier work on Mg^+. Hot plasma environments very often have fields large enough to affect this key process significantly so that understanding the effect is essential to modeling and understanding such plasmas. (Dunn)

■ **Natural Lifetime of Sodium Atom Resonance Level.** The Division completed the lifetime measurement of the Na resonant state and resolved a long-standing discrepancy between the best experiment and the best theoretical calculations. The attained lifetime accuracy was 0.22%, near the best that has ever been obtained. An important aspect of this new method is that it is subject to different systematic effects compared with the traditional atomic beam method, and may be optimum for atoms of even shorter lifetime which are increasingly difficult for traditional methods. Studies of parasitic effects, such as radiative momentum transfer during interrogation, will be of great value for understanding the true possibilities of the several atomic fountain projects being undertaken by NIST. (Hall)

■ **Noise-Immune, Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy.** Division researchers discovered/invented and applied an extremely powerful new principle that allows one to combine the signal-enhancing technique of cavity enhancement (placing the sample within an ultra-finesse cavity gives a signal enhancement of ~30,000 fold) with our earlier-developed method of optical heterodyne detection. This allows one to reach near the shot-noise-limited detection level even with real laser systems. With this method, the small residual laser-frequency noise is *not* converted into detected noise as in previous work, but rather is suppressed to below the shot-noise level. The key concept is to match the local oscillator sidebands' frequency offset to the enhancement cavity free-spectral range: in this way the noise-induced phase-shifts are made to be common mode. A detection sensitivity of $<1\times10^{-12}$ for absorption has been made, which is better by two orders of magnitude than the best results achieved to date by cavity ring-down or laser/intracavity absorption spectroscopy methods. By use of this new method and C_2HD for stabilization of a 1.064 μm laser, stability has been achieved of 3×10^{-13} at 1 s, and better than 1×10^{-14} after 1000 s. This method can be called Noise-Immune, Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy, i.e., NICE OHMS, and is the object of interest by spectroscopic research groups worldwide. (Hall)

■ **Calcium Rydberg State Alignment Effects.** An area of active control in collisions involves preparation and manipulation of orbital directions to study how the rates of processes are affected by this directionality. Division researchers developed a new method to detect aligned Rydberg states of alkali or alkaline earth atoms by a stimulated-emission "dump" pulse with a laser. Rydberg states of atomic Ca were detected from 8 d to 40 d by selectively dumping the state of interest and detecting fluorescence emission from the lower level. The first state-to-state orbital alignment experiments on Rydberg states were performed for an energy transfer process that has an observed alignment dependence, $Ca(4s18d\ ^1D_2) + Xe \rightarrow Ca(4s17p\ ^1P_1) + Xe$, by using the stimulated-emission dumping method. Through a theoretical collaboration, the state-to-state Rydberg alignment effects were predicted by quantum mechanical scattering calculations. An unanticipated velocity dependence was observed, indicating oscillations in the m-sublevel dependence, which motivates additional velocity-selected experiments in the laboratory.

State-of-the-art experiments in orbital alignment dynamics will be addressed by studying four-vector correlations on a new machine designed to study energy pooling, associative ionization, and Penning ionization processes of alkaline-earth excited states with alignment probing of final states. (Leone)

■ **Photophysics and Photochemistry in Quantum State Selected Clusters.** Division researchers have been developing high resolution tunable, optical parametric oscillators (OPOs) for use in studies of chemical reactions in quantum-state and size-selected clusters. The method is based on cw injection seeding of a 4 mirror, β-barium borate (BBO), ring resonator pumped by a single mode 355 nm laser. The resonator is servo loop locked, and therefore automatically scans with the injection seed laser, delivering up to 10 mJ of Fourier transform limited light (0.005 cm^{-1}) on both "signal" and "idler" frequencies. This is sufficient to saturate $v=3$-0 vibrational overtone transitions in OH, CH, FH, and NH chromospheres, and, as a result of vibrational Franck Condon shifts, can be used to switch on/off the subsequent breaking of the excited bond by subsequent photolysis with an excimer laser pulse. This apparatus has been used to study far-off-resonance single UV photon dissociation in HOH, HOD, and DOD, as well as vibrationally mediated photodissociation in rotationally state selected $v_{OH} = 3$ HOH molecules. The method has recently been used to study vibrationally mediated photophysics in quantum-state selected clusters of Ar with HOH and HOD. The current focus is evolving toward clusters with *reactive* channels energetically open, such as studies of HO/OD + H_2/D_2 reactions from vibrationally mediated photolysis of isotopically labeled H_2 -HOH clusters. (Nesbitt)

■ **State-to-State Inelastic Collision Dynamics in Crossed Supersonic Jets.** High sensitivity, direct IR-laser absorption methods have been developed as a powerfully general, quantum-state selective probe of inelastic collision dynamics in crossed supersonic jets. The approach is as follows. The "target" and "collider" molecules are cooled to their lowest (rotational) quantum states in a pair of supersonic jets, crossed to achieve a reasonably well defined center-of-mass collision energy. These species then interact in the single collision regime in the low density ($<10^{11}/cm^3$) region of the jet. The final states populated by these single collisions are then probed by direct absorption of a tunable IR laser propagating perpendicular to the scattering plane. Information on final-state velocity distributions can also be obtained, by high resolution analysis of the Doppler profiles. This method has been used to investigate state-to-state scattering of CH_4, HF, and H_2O with rare gases. By comparison with full, close-coupled quantum scattering calculations, these studies are now providing new tests for inelastic collision dynamics and refinement of potential-energy surfaces. (Nesbitt)

■ **IR Laser Studies of Ozone Chemical Chain Reaction Kinetics.** In the past decade there has been a steadily growing concern about the chemistry of the ozone layer, and in particular the influence of "anthropogenic" sources of chemicals on the atmosphere. One of the dominant chemical reaction cycles responsible for removal of ozone is the so-called HO_x chain cycle, $OH + O_3 \rightarrow HO_2 + O_2$ (a), and $HO_2 + O_3 \rightarrow OH + 2O_2$ (b), which cycles OH into HO_2 and back, thereby catalytically converting O_3 into O_2. This has lead to considerable concern with regard to proposed high speed air traffic in the upper troposphere and lower stratosphere, which would release considerable amounts of water vapor into what would otherwise be a quite "dry" region of the atmosphere, thus generating OH and HO_2. Kinetic information on the HO_x chain reaction has therefore assumed particular importance in developing reliable atmospheric models.

New methods have recently been developed to investigate the HO_x chain cycle by monitoring the concentrations of the OH radical with time-resolved IR laser absorption in fast flow cells. The process relies on pulsed excimer laser photolysis to produce OH radicals in a flow mixture of O_3 and buffer gases and thereby initiate the chain reaction. By detecting OH in the *near IR*, this method circumvents problems associated with LIF/resonance-fluorescence detection of OH radical, specifically, the unavoidable photolysis of O_3 by the UV probe source. This alternative IR method permits operation at more than an order-of-magnitude higher ozone concentrations, and has led to real-time detection and kinetic analysis of the HO_x chemical chain reaction under laboratory conditions. These studies indicate that the room temperature rate of the chain propagation step (a) is significantly faster (20-30%) than the values currently used in the atmospheric models. Construction of temperature-controlled flow cells will permit kinetic investigations of these chain reaction rates at temperatures relevant to the upper troposphere/lower stratosphere. (Nesbitt)

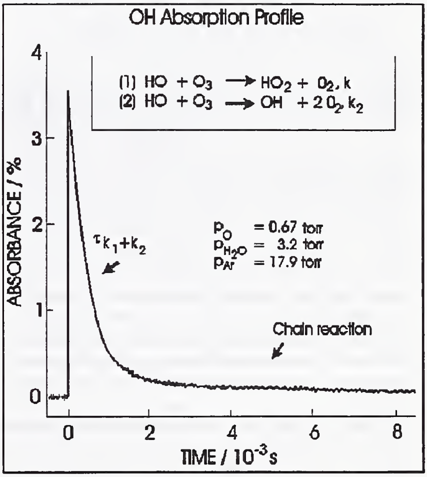


Figure 5. OH absorption profile.

■ **Femtosecond Wave-Packet Dynamics in Lithium Dimer.** The behavior of molecules prepared by ultrafast lasers and with coherent control represents an important new area of active manipulation of materials; for example, the direction of photocurrents in semiconductor quantum wells can be manipulated with coherent light fields. New experiments at JILA involve two-color preparation and probing, which give preliminary evidence that the ionization probability is dependent on internuclear separation. In addition, compositional control and pulse shaping experiments have been used to demonstrate several new effects: a new form of two-level rotational coherence spectroscopy, compositional control of the wave packet state amplitudes, and specific modification of state amplitudes by pulse shaping. (Leone)

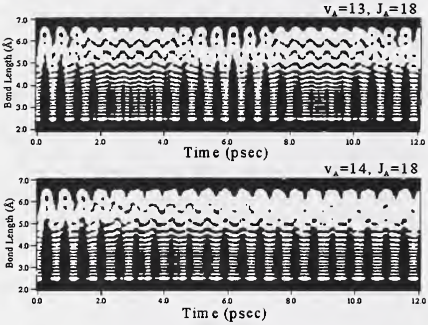


Figure 6. Manipulating wave packets.

■ **Supersonic Slit Discharges: an Intense New Source of Jet Cooled Molecular Ions and Radicals.** The vast majority of chemical reactions taking place in the atmosphere, combustion, flames, plasmas, chemical vapor depositions, semiconductor etching, etc., occur via open-shell "radical" species and/or molecular ions. The reactivity of these open-shell radicals is so much higher than the corresponding closed-shell species that they dominate the reaction kinetics, even though typically present in extremely low concentrations. It is this high reactivity that makes them a challenging species to generate in sufficient density to characterize spectroscopically under controlled gas-phase laboratory conditions.

The Division has developed new methods for generating intense sources of radicals and molecular ions, based on striking a pulsed discharge in the stagnation region behind a slit supersonic jet. This has several key advantages over more common discharge sources. First, the species are formed and then supersonically cooled down into the lowest few quantum states. Second, the molecules have their velocities collimated perpendicular to the slit direction, which is both ideal for long path, direct absorption spectroscopy with tunable lasers and for generating "sub-Doppler" absorption profiles that are as much as 10-fold narrower than under non-supersonic discharge conditions. Third, the closed-shell precursor species move supersonically in the discharge for only a few microseconds, which permits reactive species to be formed faster than they can be removed via secondary chemical reactions. These laser absorption studies have verified number densities on the order of $10^{14}/cm^3$ for radicals such as OH and CH_3, and of order $10^{12}/cm^3$ for molecular ions such as H_3^+ and H_3O^+. (Nesbitt)

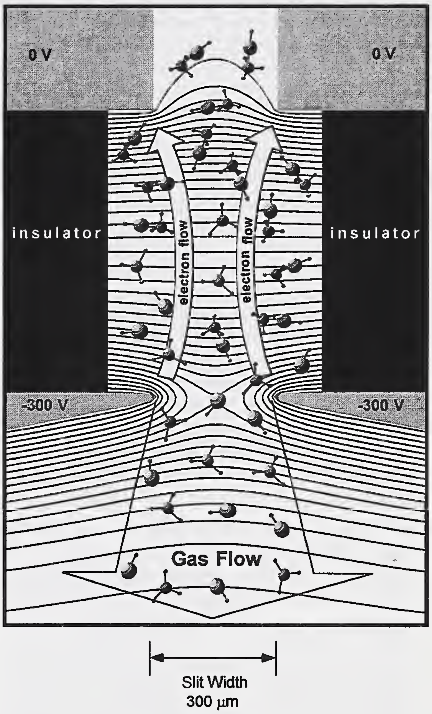


Figure 7. Slit jet discharge method. A pulsed negative voltage applied to two insulated metal jaws causes electrons to flow upstream in the expansion, with transient species being cooled to supersonic jet temperatures.

■ **Slit Jet IR Laser Spectroscopy of Combustion Radicals.** One of the most fundamental organic species relevant to fuel combustion processes is the methyl radical, CH_3. However, as a result of both its high reactivity and planar equilibrium structure (i.e., zero dipole moment), this has been an extremely elusive radical species to characterize in the gas phase. The slit jet discharge method developed in the Division now provides access to sufficient densities of CH_3 radicals under jet cooled, sub-Doppler conditions to monitor them via direct absorption in the CH stretching region. As a consequence of the high resolution and jet cooling, the near IR spectra resolve fine and hyperfine splittings due to the spin interaction between the unpaired electron spin on the C atom and the H atoms. This is the first time the so-called Fermi contact interaction has been unambiguously determined for such a fundamental radical species in the gas phase, and was found to be negative due to spin polarization of the CH bond. These results, both in sign and magnitude, are in good agreement with *ab initio* theoretical calculations. (Nesbitt)

■ **Probing the Potential Surface Topology of a Hydrogen Bond.** Although weak by comparison to normal chemical bonds, hydrogen bonding is responsible for a truly vast array of chemical, physical, and biochemical processes, ranging from the 3-dimensional folding structure of proteins to the short-range order of liquids. Any predictive understanding of such phenomena requires a detailed knowledge of the potential energy surface as a function of intermolecular geometry, i.e., the relative distances and angles of the bonding subunits. Division researchers have been developing spectroscopic methods for indirect but precise probing of the shapes of these potentials, based on high resolution IR laser absorption of hydrogen-bonded clusters in a slit jet supersonic expansion. The method exploits the high sensitivity of the long path length slit geometry to probe low frequency "hydrogen bond" modes as combination bands built on top of high frequency "intramolecular" HX stretching modes. Such work nicely complements the prospects for studies of these modes in the far-IR, but with the considerable advantage of a much wider single-mode laser scanning range in the near IR.

Recently this method has been successfully applied to one of the simplest hydrogen-bonded molecules, HF-HF and its isotopic equivalent DF-DF. As a result of the method's high resolution and sensitivity, combination band excitation into all 4 hydrogen-bond intermolecular modes has been observed for both HF-HF and DF-DF, corresponding to stretching, bending (both symmetric/antisymmetric), and twisting of the hydrogen bond. In conjunction with full 6D quantum calculations, these high resolution spectroscopic results are providing an unprecedentedly rigorous test of current state-of-the-art *ab initio* and semiempirical potentials for hydrogen bonding. As one specific example, these results indicate a significantly stronger coupling of stretching and bending degrees of freedom in the hydrogen bond than was previously predicted. (Nesbitt)

FUTURE

■ **Trapped-Atom Collisions and Wavelength Standards.** The Division has trapped strontium (Sr) atoms in a magneto-optical trap (MOT), using the 461 nm resonance line. These atoms have a rather short trap lifetime due to shelving in metastable states, and this is being addressed with additional repump lasers. When these are operational and ~1 s trap lifetimes are achieved, two applications will be followed. The Sr intercombination line offers a very narrow resonance with which the Sr atoms can be trapped at very low temperatures, by loading the relatively cold atoms from the resonance-line MOT. Transition to Sr metastable states then offers the potential for exceedingly narrow line-width visible transitions, with a natural width $\Delta\nu$ such that $\Delta\nu_N/\nu < 10^{-14}$. Depending on collisional shifts and other perturbations, these lines may provide exceptional opportunities for wavelength or frequency standards.

The second use of the trap will be to study collisions of pairs of these very cold atoms. Most studies elsewhere have been with alkali atoms or with noble gases in the metastable and higher states. The interatomic potentials are not well understood for these interacting pairs. In contrast, collisions of Sr pairs involve a minimum of molecular states that can be exceptionally well characterized. This is an ideal system for testing the myriad of assumptions and methods utilized in theories of cold collisions. Ultimately, the improved knowledge that results will allow better utilization of atom trapping for frequency standards and fundamental tests of physical principles. (Gallagher, Hall)

■ **Nonlinear Light Interactions with Matter.** Techniques developed to measure the full electric field (both amplitude and phase) of a single ultrashort laser pulse provide a new way to study, with femtosecond resolution, various aspects of the interaction of light with materials. A program has been started to extend the use of these diagnostics to areas such as materials characterization and ultrafast dynamic spectroscopy. Basic properties of electronic and optoelectronic materials can be determined by measuring the change of phase of an optical pulse after the pulse traverses a given material. This technique will be used to determine, with a high degree of accuracy, linear and nonlinear optical properties of materials such as dispersion, nonlinear refraction, and two-phase absorption, as well as other χ^3 and higher order nonlinear properties.

A novel dynamic spectroscopic technique is being developed to elucidate ultrafast processes in gaseous, liquid, and solid-state materials. This technique involves measuring the induced phase change of an ultrashort pulse after traversing a material that has been perturbed by a synchronized laser pulse with femtosecond resolution. Including phase information along with the intensity in a single shot can enhance a wide range of ultrafast experiments ranging from biophysical applications, such as exploring the kinetics of proteins, to electrical engineering and physics problems, such as examining carrier relaxation in semiconductors. (Clement)

■ **STM Assisted Near-field Scanning Optical Microscopy (NSOM).** A new project has been initiated for study of hybrid near field scanning optical microscopy assisted by scanning tunneling (STM) and atomic force microscope (AFM) methods. An STM apparatus is currently operational, and a chamber for the combined NSOM/STM efforts is constructed. An AFM is under construction. Signals are detected via fiber optic coupling of the laser-excited molecular fluorescence into a scanning double-monochrometer and dielectric notch filter for $>10^{12}$ incident light rejection. As a necessary first step, the studies will begin with fluorescence spectra and quantum yields for dye molecules spin coated on fused silica, gold, silver, and indium tin oxide surfaces. (Gallagher, Nesbitt) □

APPENDIX A

PUBLICATIONS

A

PUBLICATIONS

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APPENDIX B

INVITED TALKS

B

INVITED TALKS

LABORATORY OFFICE

Ott, W.R., "Physics Laboratory Overview and Plans," seminar organized for Hewlett-Packard on Managing Your Test and Measurement Strategy, NIST, January 1996.

Ott, W.R., "Measurement Standards and Services: What's on the Horizon," National Conference of Standards Laboratories Workshop and Symposium on Preparing Metrology for the Next Millenium, Monterey, CA, August 1996.

Saloman, E.B., "NIST Atomic and Molecular Databases on the World Wide Web," Workshop on Atomic and Molecular Data for Science and Technology, held at Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, June 1996.

Saloman, E.B., "ECSED – Where Did It Come From? Where Is It Going? Or How a Physicist Came to Establish ECSED and What Emerged," Physics Laboratory Seminar, Gaithersburg, MD, September 1996. ▫

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

U. Arp, G. Fraser, A. Hight Walker, and T. Lucatorto, "Current Status of the Infrared Synchrotron Radiation Program at SURF," Brookhaven National Laboratory, Upton, NY, May 19, 1996.

Celotta, R.J., Davies, A.D., Stroscio, J.A., and Pierce, D.T., "The Role of the Interface in the Exchange Coupled Fe/Cr/Fe System," Gordon Research Conference on Magnetic Nanostructures, Irsee, Germany, September 18, 1995.

Celotta, R.J., "Magnetic Nanostructures: A Path to Understanding Exchange Coupling," Rice University, Houston, TX, October 10, 1995.

Celotta, R.J., "Using Light to Make Nanostructures," Carleton College, Northfield, MN, October 20, 1995.

Celotta, R.J., "Nanostructure Fabrication via Laser-Focused Atomic Deposition," 40th Conference on Magnetism and Magnetic Materials, Philadelphia, PA, November 9, 1995.

Celotta, R.J., McClelland, J.J. and Gupta, R., "Making Nanostructures with Light," AAAS Annual Meeting and Science Innovation Exposition, Baltimore, MD, February 12, 1996.

Clark, C.W., "Computational Physics at NIST," American Physical Society, Washington, DC, April 19, 1995.

Clark, C.W., "Appearance Intensities for Multiply Charged Ions in a Strong Laser Field," Institute for Theoretical Atomic and Molecular Physics, Harvard University, Cambridge, MA, October 21, 1995.

Clark, C.W., "Spectroscopy of Bose-Einstein Condensates," University of Delaware, Newark, DE, November 8, 1995.

Clark, C.W., "New Angle on the Coulomb Problem," JILA Seminar, University of Colorado, Boulder, CO, December 4, 1995.

Clark, C.W., "Metrology on the Internet," 1996 Measurement Science Conference, Anaheim, CA, January 26, 1996.

Clark, C.W., "Reference Data for Electronic Structure Calculations," Naval Research Laboratory, Washington, DC, April 10, 1996.

Clark, C.W., "Structure and Spectra of Dilute Atomic Bose-Einstein Condensates," Naval Research Laboratory, Washington, DC, April 10, 1996.

Clark, C.W., "Excitation and Engineering of Atomic Bose-Einstein Condensates," Canadian Association of Physicists, University of Ottawa, Ottawa, Canada, June 18, 1996.

Clark, C.W., "Theory of Trapped Bose-Einstein Condensed Atoms," European Research Conference on Quantum Optics, Pisa, Italy, September 22, 1996.

Clark, C.W., "Structure and Spectra of Dilute Bose-Einstein Condensates," University of Toledo, Toledo, Ohio, November 14, 1996.

Clark, C.W., "Structure and spectra of dilute atomic Bose-Einstein condensates," Tulane University, New Orleans, LA, November 17, 1996.

Clark, C.W., "Structure and spectra of dilute atomic Bose-Einstein condensates," Joint Atomic Physics Colloquium, Harvard University, Cambridge, MA, December 4, 1996.

Davies, A., Stroscio, J.A., Pierce, D.T., and Celotta,R.J., "Atomic-scale Observations of Alloying at the Cr/Fe(001) Interface," E-MRS 1996 Spring Meeting, Strasbourg, France, June 5, 1996.

Davies, A., Stroscio, J.A., Pierce, D.T., Unguris, J., and Celotta,R.J., "Alloying in CrFe Multilayers," European MRS meeting, Strasbourg, France, June 6, 1996.

Davies, A., Stroscio, J.A., Pierce, D.T., Unguris, J., and Celotta,R.J., "Alloying in CrFe Multilayers," KFA - Research Center Jülich, Jülich, Germany, June 10, 1996.

Davies, A., Stroscio, J.A., Pierce, D.T., Unguris, J., and Celotta,R.J., "Alloying in CrFe Multilayers," Physics Dept., University of Bochum, Bochum, Germany, June 11, 1996.

Davies, A., Stroscio, J.A., Pierce, D.T., Unguris, J., and Celotta,R.J., "Alloying in CrFe Multilayers," Physics Dept., University of Basel, Basel, Switzerland, June 12, 1996.

Gupta, R., "Nanostructure Fabrication via Atom Optics," Microphysics of Surfaces: Nanoscale Processing, Santa Fe, NM, February 9, 1995.

Gupta, R., "Conservative Atomic Motion in Adiabatic Optical Potentials," Phys. Dept., State Univ. of New York, Stoney Brook, NY, May 12, 1995.

Gupta, R., "Nanofabrication via Atom Optics," Laboratory for Physical Sciences, College Park, MD, March 20, 1996.

McClelland, J.J., "Laser Focusing of Atoms for NanostructureFabrication,"AdvancedWorkshop on Atomic and Molecular Physics, Canberra, Australia, February 14, 1995.

McClelland, J.J., "Making Nanostructures by Focusing Atoms with Light," Wesleyan University, Middletown, CT, April 7, 1995.

McClelland, J.J., "Nanofabrication by Laser Manipulation of Atoms," Spring Joint Meeting of American Physical Society and American Association of Physics Teachers, Storrs, CT, April 8, 1995.

McClelland, J.J., "Nanofabrication Using Atom Optics, Physics Colloquium," University of Nebraska-Lincoln, Lincoln, NE, April 13, 1995.

McClelland, J.J. "Nanofabrication via Atom Optics," AAAS Annual Meeting and Science Innovation Exposition, Baltimore, MD, February 12, 1996.

McClelland, J.J., "Nanostructure Fabrication with Atom Optics, New York University, New York, NY, February 22, 1996.

McClelland, J.J. "Nanofabrication via Atom Optics," IBM Almaden Research Center, San Jose, CA April 12, 1996.

McClelland, J.J., Gupta, R. and Celotta, R.J., "Nanofabrication via Laser Focusing of Atoms," Scanning Microscopy 1996, Bethesda, MD, May 14, 1996.

McClelland, J.J., "Nanofabrication using Atom Optics," Physics Colloquium, University of Chicago, Chicago, IL, May 16, 1996.

McClelland, J.J., Gupta, R., and Celotta, R.J., "Laser Focusing of Chromium Atoms for Nanostructure Fabrication," EQEC '96, Hamburg, Germany, September 12, 1996.

McClelland, J.J., "Atom Optics with Chromium," Laboratoire Kastler-Brossel, Ecole Normale Superieure, Paris, France, September 17, 1996.

Pierce, D.T., "Influence of Thin Film Growth on the Exchange Coupling of Magnetic Multilayers," Solid State Physics Seminar, University of Texas - Austin, Austin, TX, May 9, 1995.

Pierce, D.T., "Magnetic Nanostructures: A Path to Understanding Exchange Coupling of Magnetic Layers," Pennsylvania State University, State College, PA, October 2, 1995.

Pierce, D.T., "Magnetic Nanostructures: A Path to Understanding Exchange Coupling," Physics Dept., University of Virginia, Charlottesville, VA, October 6, 1995.

Pierce, D.T., "Magnetic Nanostructures: Path to Understanding Exchange Coupling of Magnetic Layers,", Swiss Federal Institute of Technology, Zurich, Switzerland, October 26, 1995.

Pierce, D.T., "Exchange Coupling of Magnetic Layers," Fundamental Physics and Inventions in Less than Three Dimensions, Ascona, Switzerland, November 1, 1995.

Pierce, D.T., "The Role of the Interface in the Exchange Coupling of Magnetic Layers," American Physical Society, St. Louis, MO, March 18, 1996.

Pierce, D.T., Magnetic Nanostructures: A Path to Understanding Exchange Coupling, Physics Colloquium, University of Delaware, Newark, DE, April 10, 1996.

Pierce, D.T., "The Role of the Interface in the Exchange Coupling of Magnetic Layers," Solid State Physics Seminar, Ohio State University, Columbus, OH, May 22, 1996.

Stiles, M.D., "Exchange Coupling in Magnetic Multilayers, Magnetism in Multilayered and Reduced Dimensional Systems," Argonne, IL, June 20, 1995.

Stiles, M.D., "Oscillatory Exchange Coupling in Magnetic Multilayers," New England Section Meeting of the American Physical Society, Bowdoin College, Brunswick, ME, October 7, 1995.

Stiles, M.D. , "Spin-Dependent Interface Scattering," 40th Conference on Magnetism and Magnetic Materials, Philadelphia, PA, November 8, 1995.

Stiles, M.D., "Giant Magnetoresistance in Magnetic Multilayers, North Carolina State University, Raleigh, NC, January 22, 1996.

Stiles, M.D., "Oscillatory Exchange Coupling in Magnetic Multilayers," American Physical Society Tutorial "Fundamental Magnetic and Magneto-Transport Properties of Ultrathin Metallic Structures, St. Louis, MO, March 17, 1996.

Stiles, M.D., Giant Magnetoresistance in Magnetic Multilayers, Solid State Physics Seminar, Johns Hopkins University, Baltimore, MD, April 3, 1996.

Stiles, M.D., "Spin-Dependent Interface Reflection in Magnetic Multilayers," New York University, New York, NY, April 12, 1996.

Stiles, "Magnetic Multilayers," University of Vermont, Burlington, Vermont, April 17, 1996.

Stroscio, J.A., "An Atomic View of Metal on Metal Growth," Penn State University, State College, PA, April 12, 1995.

Stroscio, J.A., Pierce, D.T., Davies, A., and Celotta, R.J., "An Atomic View of the Growth of Ultra-thin Magnetic Films," American Physical Society and the American Association of Physics Teachers, Washington, DC, April 19, 1995.

Stroscio, J.A., "An Atomic View of Metal on Metal Growth," University of MD, College Park, MD, April 27, 1995.

Stroscio, J.A., "The Effect of Roughness in Fe/Cr/Fe Multilayers," 42nd National Symposium of the American Vacuum Society, Minneapolis, MN, October 17, 1995.

Stroscio, J.A., "Nucleation and Growth in Metal on Metal Epitaxy," United Kingdom Annual Scanned Probe Microscopy Meeting, St. John's College, Oxford, United Kingdom, April 10, 1996.

Stroscio, J.A., "Learning About Growth from STM Measurements," Scanning Microscopy 1996, Bethesda, MD, May 13, 1996.

Stroscio, J.A., "Atomic Scale observations of Alloying at the Cr-Fe Interface," Lehigh University, Bethlehem, PA, September 18, 1966.

Tarrio, C.S., "Multilayers for the EUV and More," University of Maryland Chemical Physics Seminar, College Park, MD, April 24, 1996.

Tarrio, C.S., "Figuring By Multilayer Deposition: A New Technique for Fabrication of Precision Optics," OSa Topical Conference on Soft X-ray Projction Lithography, Boston, MA, May 1, 1996.

Unguris, J., Kelley, M.H., Celotta, R.J., and Pierce, D.T., "Imaging Magnetic Microstructures with SEMPA," American Physical Society and the American Association of Physics Teachers, Washington, DC, April 19, 1995.

Unguris, J., "Micromagnetic Imaging Using Scanning Electron Microscopy with Polarization Analysis," Maxtor Inc., Longmont, CO, April 28, 1995.

Unguris, J. "Exchange Coupling in Magnetic Multilayers," University of Wisconsin, Madison, WI, June 14, 1996. ▫

ATOMIC PHYSICS DIVISION (842)

Arp, U., "Recent Results on the X-Ray Fluorescence of Molecules," Raman Emission by X-Rays (REX-I) Workshop, New Orleans, LA, December 1995.

Arp, U., "Atomic Physics Using Synchrotron X-Rays," Physics Laboratory Colloquium, Argonne National Laboratory, Argonne, IL, December 1995.

Bryant G.W., "Quantum Dots, Intermediate-Dimensional Excitons, and Artificial-Atom Optoelectronics," Condensed Matter Theory Seminar, Ohio State University, Columbus, OH, January 1995.

Bryant G.W., "Excitons in Complex Quantum Nanostructures," Ecole Polytechnique Federale de Lausanne (EPFL), Lausanne, Switzerland, August 1995.

Bryant G.W., "Quantum Dots and Wires: Quasiatoms to Quasimolecules and Beyond," ITAMP, Harvard University, Boston, MA, April 1996.

Bryant G.W., "Quantum Dots and Wires: Nanoscale Building Blocks for a Brave New Artificial World," University of Cincinnati, Cincinnati, OH, October 1996.

Bryant G.W., "Quantum Dots and Wires: Nanoscale Building Blocks for a Brave New Artificial World," University of Kentucky, Lexington, KY, October 1996.

Bryant G.W., "Modeling Complex Quantum Nanostructures," Army Research Laboratory, Adelphi, MD, November 1996.

Deslattes, R.D., "Thoughts on X-Ray Optics," Methods and Applications of Curved Crystal X-Ray Optics Workshop, Institut Laue Langevin, Grenoble, France, May 1995.

Deslattes, R.D., "Optomechanical and Precision Instrument Design," SPIES 1995 International Symposium on Optical Science, Engineering and Instrumentation, San Diego, CA, July 1995.

Deslattes, R.D., "Precision Mechanics for Optical Components," SRI 95 – APS X-Ray Centennial Symposium and Seventh Users Meeting for the American Physical Society, Argonne National Laboratory, Argonne, IL, October 1995.

Deslattes, R.D., "Counting Atoms and Weighing Photons: Physics Applications of Optomechanics," Precision Engineering Laboratory, Univ. North Carolina, Charlotte, NC, November 1995.

Deslattes, R.D., "Raman Entanglement in Threshold Spectra," Raman Emission by X-Rays (REX-I) Workshop, New Orleans, LA, December 1995.

Deslattes, R.D., "Prospects for X-ray Emission Spectroscopy at APS," Atomic Physics with Hard X-rays from High Brilliance Using a Synchrotron Source, Argonne National Laboratory, Argonne, IL, May 1996.

Deslattes, R.D., Kessler, E.G., Schweppe, J.E., "Intercomparison of Silicon Samples from the Avogadro Project," Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 1996.

Deslattes, R.D., "Parallel Beam Powder Diffraction Using Laboratory X-Ray Sources," Combined Meeting of the 45th Annual Denver X-Ray Conference and the Powder Diffraction Satellite Meeting, Denver, CO, August 1996.

Gillaspy, J.D., "EBIT Spectra of Highly Stripped Ions from the Visible to the X-ray," 5th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, Meudon, France, August 1995.

Gillaspy, J.D., "Ion-Surface Experiments at the NIST EBIT Facility," Lawrence Livermore National Laboratory, Livermore, CA, July 1996.

Gillaspy, J.D., "Overview of the NIST EBIT Project," Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Hungary, July 1996.

Gillaspy, J.D., "Ion-surface Collisions with Low-Energy Highly-Charged Beams," Fourteenth International Conference on the Application of Accelerators in Research and Industry, Denton, TX, November 1996.

Gillaspy, J.D., "The Electron Beam Ion Trap and its Application to Nanotechnology," University of Florida, Gainsville, FL, November 1996.

Helmerson, K., "Progress Towards BEC of Sodium Atoms in a TOP Trap," IQEC Satellite Workshop on Atom Optics, Cairns, North Queensland, Australia, July 1996.

Helmerson, K., "Optical Tweezers," University of Sao Poulo Seminar, Sao Carlos, Brazil, July 1995.

Helmerson, K., "Optical Tweezers," Federal University Seminar, Rio de Janeiro, Brazil, July 1995.

Helmerson, K., "Atom Optics at NIST," Quantum Optics Workshop, Snowbird, UT, January 1995.

Kim, Y.-K., "Relativistic Modifications of Charge Expansion Theory," European Research Conference on Relativistic Effects in Heavy-Element Chemistry and Physics, Il Ciocco, Italy, March 1995.

Kim, Y.-K., "New Model for Electron-Impact Ionization Cross Sections of Atoms and Molecules," 3rd Symposium on Laser Spectroscopy, Taejon, Korea, November 1995.

Julienne, P.J., "How Light Changes the Collision Rates of Cold, Trapped Atoms," Harvard University, Cambridge, MA, November 1995.

Julienne, P.J., "Optical Modification of Ultracold Atomic Collisions," Workshop on Laser-Induced Interactions in Atomic Collisions, Bad Honef, Germany, March 1996.

Julienne, P.J., "Atomic Collisions in a Bose-Einstein Condensate," Symposium on Bose-Einstein Condensation, CLEO/QELS Meeting, Anaheim, CA, June 1996.

Julienne, P.J., "Collisions in a Cold Atomic Gas," Univ. Rochester, Rochester, NY, June 1996.

Julienne, P.J., "Photoassociation Spectroscopy: A Precision Measurement Tool for Interatomic Interactions in a Cold Atomic Gas," JILA Workshop on Bose-Einstein Condensation, Boulder, CO, July 1996.

Julienne, P.J., "Photoassociation Spectroscopy: A Precision Measurement Tool for Interatomic Interactions in a Cold Atomic Gas," Gordon Conference on Simple Systems in Chemistry and Physics, Andover, NH, August 1996.

Kim, Y.-K., "New Theoretical Model for Electron-Impact Ionization Cross Sections of Atoms and Molecules," Pohang University of Science and Technology, Pohang, Korea, November 1995.

Kim, Y.-K., "New Model for Electron-Impact Ionization Cross Sections of Atoms and Molecules," 10th APS Topical Conference on Atomic Processes in Plasmas, San Francisco, CA, January 1996.

Kim, Y.-K., "Strengths and Weaknesses of Relativistic Atomic Structure Calculations," 9th Int. Conference on the Physics of Highly Charged Ions, Omiya, Japan, September 1996.

Kim, Y.-K., "Relativistic Atomic Structure Theory," University of Electro-Communications, Chofu, Japan, September 1996.

Kim, Y.-K., "Electron-Impact Ionization Cross Sections of Environmentally Sensitive Molecules," 3rd Asian International Seminar on Atomic and Molecular Physics, Pohang, Korea, October 1996.

Kim, Y.-K., "Atomic Structure Calculations for Fusion Applications," Workshop on the Role of Atomic Physics and Atomic Data Centers in Fusion, Taejon, Korea, October 1996.

Kim, Y.-K., "New Theory for Electron-Impact Ionization Cross Sections of Atoms and Molecules," 49th Annual Gaseous Electronics Conference, Argonne, IL, October 1996.

Lett, P., "Photoassociative Ionization Spectroscopy of Ultracold Na," Temple University, Philadelphia, PA, February 1995.

Lett, P., "Photoassociation in Ultracold Collisions: High Resolution Spectroscopy from the Collision Continuum," 19th International Conference on the Physics of Electronic and Atomic Collisions, Whistler, Canada, August 1995.

Lett, P., "Photoassociative Spectroscopy of Laser Cooled and Trapped Atoms," American Chemical Society, Anaheim, CA, April 1995.

Lett, P., "Ultracold Collisions of Laser-Cooled Atoms," Optical Sciences Center, University of Arizona, Tucson, AZ, April 1995.

Lett, P., "Photoassociative Spectroscopy of Ultracold Laser Cooled Sodium," Laser Interactions Conference on Laser Assisted Dynamic Interactions, Crete, May 1995.

Lett, P., "Observation of Retardation and Measurement of the Atomic Na (3P) Lifetime by Molecular Spectroscopy," University of Chicago, Chicago, IL, November 1995.

Lett, P., "Measurement of the Atomic Na(3P) Lifetime and of Retardation in the Interaction between Two Atoms Bound in a Molecule," University of Connecticut, Storrs, CT, February 1996.

Lett, P., "Measurement of the Atomic Na(3P) Lifetime and of Retardation in the Interaction between Two Atoms Bound in a Molecule," Wesleyan University, Middletown, CT, February 1996.

Lett, P., "Measurement of the Atomic Na(3P) lifetime and of retardation in the Interaction Between Two Atoms Bound in a Molecule," Rensselaer Polytechnic Institute, Troy, NY, February 1996.

Lett, P., "Laser Cooling of Neutral Atoms," Creighton University, Omaha, NE, February 1996.

Lett, P., "Laser Cooling and Trapping of Neutral Atoms," Hampton University, Hampton, VA, March 1996.

Lett, P., "Learning about atoms and their interactions from photoassociation spectroscopy," HCM Network -V Workshop, Island of Vulcano, Italy, September 1996.

Lett, P., "Progress towards BEC in Na at NIST, Gaithersburg," HCM Network -V Workshop, Island of Vulcano, Italy, September 1996.

Mies, F.H., "Adiabatic Field Dressed Molecular States in Intense Laser Fields," DAMOP Symposium, American and Canadian Physics Society Meeting, Toronto, Canada, May 1995.

Mies, F.H. "Angular Asymmetries in Strong Field Dissociation of H2+ and HD+," Multiphoton Processes in High Fields Symposium, Dead Sea, Israel, February 1996.

Mies, F.H., "Coherent Control of Ionization and Dissociation Dynamics Using Half Cycle Laser Pulses," The Bat-Sheva Seminar on Coherent Control, Neve Ilan, Israel, March 1996.

Mies, F.H., "A Generalized Multichannel Quantum Defect Analysis of the O_2 Schumann-Runge Predissociation," Australian National University, Canberra, Australia, August 1996.

Mohr, P.J., "QED Effects in High-Z Few-Electron Atoms," Howard University, Washington, DC, March 1995.

Mohr, P.J., "Status of the 1997 Least Squares Adjustment of the Fundamental Constants," APS/AAPT meeting, Indianapolis, IN, April 1996.

Mohr, P.J., "Quantum Electrodynamics and the Fundamental Constants," Modern Trends in Atomic Physics, Nobel sponsored symposium, Gothenburg, Sweden, May 1996.

Mohr, P.J., "Databases on the World-Wide Web," 10th APS Topical Conference on Atomic Processes in Plasmas, San Francisco, CA, January 1996.

Mohr, P.J., "Quantum Electrodynamics of High-Z Few-Electron Atoms," 50th Anniversary of the Discovery of the Lamb Shift, Bellingham, WA, August 1996.

Phillips, W.D., "Laser Cooling, Optical Lattices, and the Coldest Temperatures ever," University of New Mexico, Albuquerque, NM, March 1995.

Phillips, W.D., "Atomics in Optical Lattices," Atomic Physics Gordon Conference, Wolfeboro, NH, July 1995.

Phillips, W.D., 3 Lectures on Laser Cooling and Trapping, Enrico Fermi Summer School on Collective and Coherent Interactions of Particles and Radiation Beams, Varenna, Italy, July 1995.

Phillips, W.D., "Quantum Motion of Atoms in Optical Lattices," Symposium on Quantum and Coherent Effects, Tokyo, Japan, August 1995.

Phillips, W.D., "Laser Cooling of Neutral Atoms," 5th Symposium on Frequency Standards and Metrology, Woods Hole, MA, October 1995.

Phillips, W.D., "Laser Cooling of Neutral Atoms," Stockholm University, Stockholm, November 1995.

Phillips, W.D., "Optical Lattices: condensed matter with atomic gases," University of Göteborg, Göteborg, Sweden, November 1995.

Phillips, W.D., "Recent Advances in Laser Cooling," Swedish Physics Society, Uppsala, Sweden, November 1995.

Phillips, W.D., "Hot New Physics with Old Cold Atoms," American Association for the Advancement of Science Annual Meeting, Baltimore, MD, February 1996.

Phillips, W.D., "New Measurements on Laser Cooling: Bragging about Optical Lattices," Massachusetts Institute of Technology, Cambridge, MA, February 1996.

Phillips, W.D., "Laser Cooling: the Coldest Atoms ever," Mechanical and Aerospace Engineering Colloquium, Princeton, NJ, March 1996.

Phillips, W.D., "Progress toward Bose Condensation at NIST-Gaithersburg," Les Houche Workshop on Bose Condensation, Les Houches, France, April 1996.

Phillips, W.D., "Optical Lattices: Atomic Physics Meets Solid State," Massachusetts Institute of Technology, Cambridge, MA, April 1996.

Phillips, W.D., "Laser Cooling of Atoms," Minnesota Academy of Science Annual Meeting, St. Paul, MN, April 1996.

Phillips, W.D., "Atomic Clocks, Einstein, and the Coldest Atoms Ever," Minnesota Academy of Science Annual Meeting, St. Paul, MN, April 1996.

Phillips, W.D., "Laser Cooling and Trapping of Atoms," Michelson Medal Lecture, University of Pennsylvania, Philadelphia, PA, May 1996.

Phillips, W.D., "Controlling the Motion of Atoms in an Optical Lattice," 3rd Workshop on Optics and Interferometry with Atoms, Elba, Italy, June 1996.

Phillips, W.D., "Laser Cooling and the Future of Atoms in Optical Lattices," European Research Conference, Castelvecchio, Italy, September 1996.

Phillips, W.D. "Quantum Motion of Atoms Confined in an Optical Lattice," 6th NEC Symposium on Fundamental Approaches to New Material Phases: Quantum Optical Phenomena in Spatially Confined Systems, Karuizawa, Japan, October 1996.

Phillips, W.D., "Quantum Motion of Atoms Confined in an Optical Lattice," Symposium on Quantum Optics, Tokyo, Japan, October 1996

Phillips, W.D., "Time, Einstein and the Coldest Atoms Ever," Pennsylvania State University, State College, PA, November 1996.

Phillips, W.D., "Optical Lattices: Atomic Physics Meets Solid State," Pennsylvania State University, State College, PA, November 1996.

Phillips, W.D., "Do we understand laser cooling," Pennsylvania State University, State College, PA, November 1996.

Phillips, W.D., "Time, Einstein and the Coldest Atoms Ever," Truman State University, Kirksville, MO, November 1996.

Phillips, W.D., "Optical Forces: Comet Tails to Cells to Atoms," Truman State University, Kirksville, MO, November 1996.

Roberts, J.R., "Studies with Very Highly Charged Ion Beams," R&D Technology Workshop on Ion Beams and Reverse Engineering, National Security Agency, Linthicum, MD, February 1996.

Roberts, J.R., "UV Source and Detector Radiometry for Microlithography," SPIE Short Course at Microlithography 1996, Sana Clara, CA, March 1996.

Rolston, S.L., "Laser cooled atoms: the coldest things around," Johns Hopkins Applied Physics Laboratory, Columbia, MD, January 1995.

Rolston, S.L., "Laser cooled atoms: the coldest things around," Brookhaven National Laboratory, Upton, NY, January 1995.

Rolston, S.L., "Optical shielding of collisions," American Physical Society, San Jose, CA, March 1995.

Rolston, S.L., "Laser Cooling at NIST," American Physical Society, Washington, DC, April 1995.

Rolston, S.L., "Optical Lattices," DAMOP, Toronto, Canada, May 1995.

Rolston, S.L., "Recent Results at NIST," Ecole Normale Superiuer, Paris, France, June 1995.

Rolston, S.L., "Optical Lattices," 12th Intl. Conf. on Laser Spectroscopy, Capri, Italy, June 1995.

Rolston, S.L., "Laser cooled atoms: the coolest things around," Washington University, St. Louis, MO, September 1995.

Rolston, S.L., "Optical Lattices," Atomic Physics Seminar, Yale University, New Haven, CT, October 1995.

Rolston, S.L., "Laser-cooled atoms: the coolest things around," Indiana University, Bloomington, IN, February 1996.

Rolston, S.L., "Optical Lattices," Harvard University, Cambridge, MA, September 1996.

Tang, C-M., "Theory and Experiment of Field-Emitter Arrays with Planar Lens Focusing," 8th International Vacuum Microelectronics Conference, Portland, Oregon, July 1995.

Tang, C.-M., "Microelectronic Applications for Accelerator RF Power," 1995 Particle Accelerator Conference and International Conference on High-Energy Accelerators, Dallas, TX, May 1995.

Wiese, W.L., "The New Atomic Spectroscopic Databases at NIST," 13th meeting of IAEA Data Center Network, Intl. Atomic Energy Agency, Vienna, Austria, July 1995.

Wiese, W.L., "Optical Emission Spectroscopy for Ionized Nitrogen and Oxygen," University of Graz, Austria, July 1995.

Wiese, W.L., "The NIST Spectroscopic Database and Two New Critical Data Tables," 10th Topical APS Conf. on Atomic Processes in Plasmas, San Francisco, CA, January 1996.

Wiese, W.L., "Oscillator Strengths for Light Elements – Program and Problems," Jagellonian University, Krakow, Poland, and Central Research Institute, Budapest, Hungary, September 1996.

Wiese, W.L. "Determination of Atomic Oscillator Strengths for Nitrogen and Oxygen Lines with a Wall-Stabilized Arc Source," University of Kiel and University of Hannover, Germany, September 1996.

Wiese, W.L., "Laboratory Tests of the Spectroscopic Coupling Scheme in Nitrogen I and II," Ruhr University, Bochum, Germany, October 1996.

Wiese, W.L., "Atomic Oscillator Strengths for Light Elements," 4th Symposium on Laser Spectroscopy, Taejon, South Korea, November 1996. ▫

OPTICAL TECHNOLOGY DIVISION (844)

Asmail, C., "Final Report on Bidirectional Scattering Metrology Project," CCG Project Review Meeting, NIST, Gaithersburg, MD, September 1995.

Barnes, Y., "STARR Facility in Conjunction with Standard Development Efforts using Bidirectional Geometries," CORM Conference, Gaithersburg, MD, May 1996.

Barnes, Y., "Earth Observation Station (EOS): Bidirectional Reflectance Distribution Function (BRDF) Round-Robin," SIRREX-5 Conference, National Institute of Standards and Technology, Gaithersburg, MD, July 1996.

Barnes, Y., "Bidirectional Reflectance Distribution Function (BRDF) Measurements of Diffusers," EOS Calibration Conference, NASA/GSFC, Beltsville, MD, July 1996.

Casassa, M.P., "Time- and State-resolved Dynamics of O-atom Reactions," 1996 AFOSR Molecular Dynamics Contractor's Meeting, Boulder, CO, June 1996.

Cromer, C., "Calibration of Tristimulus Colorimeters for Color Displays," CORM Conference, Gaithersburg, MD, May 1996.

Datla, R.U., "Current Capabilities and Ongoing IR Development Activities at NIST", Workshop on Standards for IR-FPAs & Imaging Systems for DoD/BMDO Applications, NIST, Gaithersburg, MD, September 1995.

Datla, R.U., "Cryogenic Radiometry at NIST", All-Russian Research Institute for Optophysical Measurements (VINIIOFI), Ozernaya, Moscow, Russian Federation, October 1995.

Datla, R.U., "Radiometric Standards and IR spectrophotometry at NIST", National Physical Laboratory, New Delhi, India, November 1995.

Datla, R.U., "Radiometric Calibrations Program for the Infrared at NIST", Space Applications Center, Indian Space Research Organization, Ahmedabad, India, November 1995.

Datla, R.U., "Magneto-Raman Scattering Facility at the Radiometric Physics Division at NIST," Andhra University, Waltair, India, November 1995.

Datla, R.U., "Capabilities at NIST for High Accuracy Measurements of the Optical Properties of Materials," SPIE Optical Materials Working Group Meeting, Denver, CO, August 1996.

Dummer, D. and Zong, Y, "Development of Transmittance Spectrophotometry from the Ultraviolet to the Thermal Infrared," CORM Conference, Gaithersburg, MD, May 1996.

Dummer, D. and Hanssen, L., "Development of Optical Polarization Metrology," CORM Conference, Gaithersburg, MD, May 1996.

Eppeldauer, G. and Ohno, Y., "Illuminance/Luminance Standard Photometers," CORM Conference, Gaithersburg, MD, May 1996.

Fraser, G.T., "Reducing the Large Amplitude Motions in Ammonia Dimers by Deuteration", Gordon Conference on Molecular and Ionic Clusters, Oxnard, CA, January 1995.

Fraser, G.T., "Spectroscopic Studies of Intermolecular Forces," George Washington University, Washington, DC, March 1995.

Fraser, G.T., "The Van der Waals Interactions of Ammonia," Wesleyan University, Middletown, CT, October 1995.

Fraser, G.T., "Spectroscopy and Structure of the Water Dimer," Gordon Conference, Plymouth, NH, August 1996.

Fraser, G.T., "Spectroscopic Studies of Hydrogen Bonding," University of Virginia, Charlottesville, VA, September 1996.

Fraser, G.T., "Spectroscopic Studies of Hydrogen Bonding," Howard University, Washington, D.C., September 1996.

Fraser, G.T., "Spectroscopic Studies of Hydrogen Bonding," University of Maryland, College Park, MD, September 1996.

Germer, T., "Optical Scattering from Silicon Wafers and Other Smooth Surfaces," CORM Conference, Gaithersburg, MD, May 1996.

Germer, T., "Proposed Methodology for Characterization of Microroughness-induced Optical Scatter Instrumentation," Annual Meeting of the Society of Photo-optical Instrumentation Engineers, Denver, CO, August 1996.

Goldner, L., "Issues In and Applications of Near Field Optics," University of South Florida, Tampa, FL, November 1995.

Goldner, L., "Atom Optics and Interferometry in the Dark State," Universität Kaiserslautern Sonderseminar, Kaiserslautern, Germany, May 1995.

Goldner, L., "Optical Characterization at the Nanoscale using Near-Field Scanning Optical Microscopy," CORM Conference, Gaithersburg, MD, May 1996.

Gupta, R., McClelland, J.J., and Celotta, R.J., "Nanofabrication via Atom Optics," Laboratory for Physical Sciences, College Park, MD, March 1996.

Gupta, R., McClelland, J.J., Jabbour, Z.J., Celotta, R.J., and Marte, P., "Observation of $\lambda/8$ Atomic Spatial Distribution in an Optical Potential," State University of New York, Stony Brook, NY, September 1995.

Hanssen, L., "Integrating Sphere for Absolute Infrared Diffuse Reflectance Measurement," CORM Conference, Gaithersburg, MD, May 1996.

Hanssen, L., "IR Optical Property Measurements Using Fourier Transform Instrumentation," CORM Conference, Gaithersburg, MD, May 1996.

Hardis, J.E., "Improved Color Measurements of Displays," CORM Conference, Gaithersburg, MD, May 1996.

Heilweil, E.J., "Hydrogen-bond and Vibrational Up-pumping Dynamics Studied by Broadband Transient Infrared Spectroscopy," TRVS VII, Sante Fe, NM, June 1995.

Heilweil, E.J. (with C. Schmuttenmaer), "Ultrafast Infrared Studies of Solution-phase Hydrogen-Bonding Reactions: Kinetics, Equilibrium Dynamics, and Vibrational Energy Conservation," Yale University, New Haven, CT, April 1996.

Hight Walker, A.R., "Current Status of the Infrared Synchrotron Radiation Programs at SURF II," Workshop on the Utilization of Infrared Synchrotron Radiation; National Light Source, Brookhaven National Laboratory, Brookhaven, NY, May 1996.

Hight Walker, A.R., "Using Synchrotron Radiation as a Source for Spectroscopy," Wesleyan University, Middletown, CT, September 1996.

Hight Walker, A.R., "Exploring Industrial Applications of Fourier-Transform Microwave Spectroscopy," DOW Chemical, Freeport, TX, October 1996.

Hight Walker, A.R., "Using Fourier-Transform Microwave Spectroscopy for Trace Gas Analysis," Houston Area Spectroscopy Society; Houston, TX, October 1996.

Hougen, J.T., "Attempts to Understand Pseudo-rotation in the Na_3 Molecule," University of Wisconsin, Madison, WI, March 1995.

Jacox, M.E., ,"Infrared Spectra of Free Radicals and Molecular Ions Derived from First- and Second-Row Fluorides and Chlorides," Gordon Research Conference on the Chemistry and Physics of Matrix-Isolated Species, Plymouth, NH, August 1995.

Jacox, M.E., "The Vibrational Spectra of BCl_2^+, BCl_3^+, and BCl_3^- Trapped in Solid Neon," 23rd International Symposium on Free radicals, Victoria, BC, Canada, August 1995.

Jacox, M.E., "Shedding Light on the Structures and Chemical Bonding of Molecular Ions." Catholic University of America, Washington, DC, October 1995.

Johnson, B.C., "Radiation Thermometer Temperature Standards at NIST," NRLM, Tsukuba, Japan, February 1995.

Johnson, B.C., "Cross Calibration of Optical Sensors on Satellites, Chino Corporation, Tsukuba, Japan, February 1995.

Lafferty, W.J., "Spectroscopic Studies at NIST to Support the Monitoring of Atmospheric Chemistry," Howard University, Washington, DC, February 1995.

Lafferty, W.J., "Applications of High Resolution Spectral Data as Applied to the Quantitative Intensity Determination of the 2500 cm^{-1} Atmospheric Window Band of SO_2," 88th Annual Meeting and Exhibition, San Antonio, TX, June 1995.

Lovas, F.J., "Pulsed-Beam Fourier Transform Microwave Spectroscopy: Research and Applications," Optical Society of America, Santa Fe, NM, February 1995.

Lovas, F.J., "Small Molecular Complexes - Structure and Dynamics Studied by Fourier-Transform Microwave Spectroscopy," National Institute for Advanced Interdisciplinary Research Workshop on Cluster Science, Tsukuba, Japan, March 1995.

Lovas, F.J., "Pulsed-Beam Fourier Transform Microwave Spectroscopy: Research and Applications," Kyushu University, Fukuoka, Japan, March 1995.

Migdall, A.L., "Intrinsically Absolute Radiance Measurements using Correlated Photons," SPIE Annual Meeting, Denver, CO, August 1996.

Ohno, Y., "Realization of the new NIST Luminous Flux Scale," National Physical Laboratory, UK, June 1995.

Ohno, Y., "Analysis of Integrating Sphere Spatial Nonuniformities by Computer Simulation," CORM Conference, Gaithersburg, MD, May 1996.

Ohno, Y. (NIST) and Salter, G. (PTB, Germany), "Comparison of Sphere Photometer and Goniophotometry for Different Types of Lamp Source," CORM Conference, Gaithersburg, MD, May 1996.

Ohno, Y., "NIST Detector-based Photometric Scales and Calibration Procedures," National Physical Laboratory, New Delhi, India, November 1995.

Pine, A.S., "Collision Dynamics Studied by Pressure Broadenings and Shifts, Dicke Narrowing, Correlations and Line Mixing," CCP6 Workshop on Inelastic Collisions and Dynamics in the Atmosphere, University of Durham, Durham, England, July 1995.

Pine, A.S., "Tunable Laser Spectroscopy from Near to Far Infrared," Universities of Cologne and Bonn, Bonn, Germany, July 1995.

Pine, A.S., "A New Terahertz Photomixer for Far-Infrared Spectroscopy of Atmospheric Species," 27th Annual Meeting of the Division of Planetary Sciences of the American Astronomical Society, Kona, Hawaii, October 1995.

Rice, J.P., "Thermal Infrared Transfer to EOS," Sixth SDL/SUS Symposium on Infrared Radiometric Sensor Calibration, Logan, UT, May 1996.

Sergienko, A.V., Pittman, T.H., Streaklov, D.V., Rubin, M.H., Shih, Y.H., Datla, R., and Migdall, A.L., "Demonstration of Two-Photon Interference with Postponed Compensation and 'Quantum Vernier' Effect," CLEO/Europe-EQEC'96, September 1996.

Shirley, E.L., "Sheets, Chicken-wire Tubes, and Soccer Balls," Georgetown University, Washington, DC, January 1995.

Shirley, E.L., "Sheets, Chicken-wire Tubes, and Soccer Balls," Ohio State University, Columbus, OH, April 1995.

Shirley, E.L., "Synchrotron Radiation Studies of Graphitic Carbon," Materials Modeling Workshop, Naval Research Laboratory, Washington, D.C., October 1996.

Shirley, E.L., "X-ray Inelastic Scattering in Graphite and Boron Nitride," Raman Emission of X-rays Conference, New Orleans, LA, December 1995.

Shirley, E.L., "Synchrotron Radiation Studies of LiF, Graphite and h-BN: Modeling Complex Spectra of Simple Materials," Condensed Matter Theory Workshop, Argonne National Laboratory, Argonne, IL, June 1996.

Shirley, E.L., "Sheets, Chicken-wire Tubes, and Soccer Balls," Virginia Commonwealth University, Richmond, VA, September 1996.

Shirley, E.L., "Carbons and Boron Nitrites, Twin Sons of Different Mothers," Condensed Matter Seminar, Brookhaven National Laboratory, Upton, NY, December 1996.

Suenram, R.D., "Fourier Transform Microwave Spectroscopy: A New Tool for Analytical Chemists," University of Kansas, Lawrence, KS, November 1995.

Suenram, R.D., "Fourier Transform Microwave Spectroscopy: A New Tool for Analytical Chemists," Kansas State University, Manhattan, KS, November 1995.

Suenram, R.D., "Using Fourier Transform Microwave Spectroscopic Techniques to Detect and Monitor Chemical Agents," Army Research Laboratory, Fort Monmouth, NJ, August 1996

Suenram, R.D., "Modern Techniques in Far-Infrared Spectroscopy," Analytical and Engineering Sciences, Dow Chemical Co, Freeport, Texas, October 1996. □

IONIZING RADIATION DIVISION (846)

Adams, J.M., "Bonding Symmetry of GaAs(111)B Semiconductor Surfaces Characterized by Surface Electric-Field Gradients," University of Illinois at Urbana-Champagne, IL, March 1995.

Adams, J.M., "Traceable Fluence Measurement Calibrations from a ^{252}Cf Field to Another Spectrum," Californium-252 Workshop, Oak Ridge National Laboratory, Oak Ridge, TN, April 1995.

Adams, J.M., "The Role of ^{237}Np in Reactor Pressure Vessel Dosimetry," Fourth Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, National Institute of Standards and Technology, Gaithersburg, MD, November 1995.

Adams, J.M., "The Materials Dosimetry Reference Facility Round Robin Tests of ^{237}Np and ^{238}U Fissionable Dosimeters," Ninth International Symposium on Reactor Dosimetry, Prague, Czech Republic, September 1996.

Beckles, V. (with Thomas, J. and Inn, K.G.W.), "Determination of ^{210}Pb in NIST Ashed Bone by Gamma-ray Spectroscopy," 42nd Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, San Francisco, CA, November 1996.

Burnett, W. (with Schultz, M., Inn, K.G.W., Thomas, J.W.L. and Lin, Z.-C.), "Radionuclide Speciation – The Key to Transport and Fate?" 4th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, Washington, DC, November 1995.

Carlson, A.D., "Improvements to the ^{10}B(n,alpha) Standard Cross Sections," Nuclear Energy Agency Nuclear Science Committee-Working Party on International Evaluation Cooperation, Paris, France, May 1995.

Carlson, A.D., "Status of the Neutron Cross Section Standards," Cross Section Evaluation Working Group, Brookhaven National Laboratory, Upton, NY, October 1995.

Carlson, A.D., "Status of the Subgroup Working on the ^{10}B(n,alpha) Standard Cross Sections," Nuclear Energy Agency Nuclear Science Committee-Working Party on Nuclear Data Measurement Activities, Argonne National Laboratory, Argonne, IL, June 1996.

Coursey, B.M., "Research Opportunities at the NIST MIRF," Catholic University, Washington, DC, January 1995.

Coursey, B.M., "History of Radiochromic Systems and Their Chemical Mechanisms," American Association of Physicists in Medicine, Philadelphia, PA, June 1996.

Coursey, B.M., "Standards and Measurements for Therapeutic Radionuclides," American Association of Physicists in Medicine, College Park, MD, June 1996.

Coursey, B.M., "Ultra Low-Level Radioimmunoassays," International Symposium on Radioiodine, Mayo Clinic, Rochester, MN, August 1996.

Coursey, B.M., "NIST Standards for Radioiodines," International Symposium on Radioiodine, Mayo Clinic, Rochester, MN, August 1996.

Coursey, B.M., "100 Years of Radioactivity in Medicine," Colloquium, National Institute of Standards and Technology, October 1996.

Desrosiers, M.F., "Retrospective Assessment of Radiation Overexposure Using Tooth Enamel," The Hebrew University of Jerusalem, Israel, April 1995.

Desrosiers, M.F., "Tooth Enamel Dosimetry: Current Status and Measurement Issues," Office of International Health Studies, Department of Energy, Washington, DC, May 1995.

Desrosiers, M.F., "Current Status of the EPR Detection Method for Irradiated Foods," Fourth International Symposium on ESR Dosimetry and Applications, Munich, Germany, May 1995.

Desrosiers, M.F., "EPR Metrology at NIST," Pittsburgh Conference, Chicago, IL, March 1996.

Dewey, M.S., "Review of Neutron Beta Decay," XXXth Recontres de Moriond, Villars, Switzerland, January 1995.

Dewey, M.S., "The Neutron Lifetime and Decay Correlations in Neutron Decay," Washington, DC, American Physical Society, April 1995.

Dewey, M.S., "Neutrons, the Standard Model and Big Bang Nucleosynthesis," University of Maryland, College Park, MD, October 1995.

Humphreys, J.C., "Overview of Criteria for Selection of Dosimetry Systems for Various Irradiation Processes," Third International Dosimetry Workshop for Radiation Processing, Ste-Adele, Quebec, Canada, October 1995.

Inn, K.G.W., "NIST MQA Programs for Environmental Radioactivity and Radiation Monitoring," 4th Symposium on Environmental Radiation Monitoring Technology; Kaohsiung, Taiwan, April 1995.

Inn, K.G.W., "Standards and the Role of NIST," New England Radiological Health Committee's (NERHC) Environmental and Radiation Laboratory Workshop, Winchester, MA, April 1995.

Inn, K.G.W., "The Council on Ionizing Radiation Measurements and Standards (CIRMS): A Technology Forum," Health Physics Society, Boston, MA, July 1995.

Inn, K.G.W. (with Lin, Z.-C.), "The NIST Low-Level Radionuclide Ocean Sediment Standard Reference Material," International Committee for Radionuclide Metrology Low-Level Working Group, Seville, Spain, October 1995.

Inn, K.G.W. (with Lin, Z.-C.), "Determination of Trace Concentrations of Actinides in the NIST Bone Ash Standard Reference Materials Using TRU-Spec Extraction Resin," 4th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, Gaithersburg, MD, November 1995.

Inn, K.G.W., "Preparation, Certification and Uses of NIST SRM's," Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Boston, MA, November 1995.

Inn, K.G.W., "Radioactivity Standards at NIST," Operational Health Physics, Georgetown U., Washington, DC, November 1995.

Inn, K.G.W., "NIST Radioactivity Measurement Quality Assurance Programs," Workshop on Radiochemistry Quality Assurance, Carlsbad, NM, July 1996.

Inn, K.G.W., "NIST Natural Matrix SRMs: The Next Generation," American Chemical Society and US Environmental Protection Agency Annual Waste Testing & Quality Assurance Symposium, Washington, DC, August 1996.

Inn, K.G.W., "Environmental Radiochemistry MQA Programmatic Issues," 42nd Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, San Francisco, CA, November 1996.

Jones, G.L., "Beta Asymmetry ^{19}Ne as a Test of a Standard Model," Williams College, Williamstown, MA, November 1996.

Karam, L.R., "Fullerene Encapsulation of ^{99m}Tc: A Novel Radionuclidic Carrier," Industrial Radiation and Radioisotope Measurements and Applications (IRRMA), Raleigh, NC, October 1996.

Kuruvilla, L.E. (with McCurdy, D.E., Inn, K.G.W., and Barss, N.M.), "Preparation and Certification of Performance Evaluation Materials: ^{239}Pu in Artificial Urine at the μBq ($\sim$100 aCi) Level," 42nd Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, San Francisco, CA, November 1996.

Lin, Z.-C. (with Inn, K.G.W.), "Determination of The Low-Level Radioactivity Ocean Sediment Standard Reference Material," 41st Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Boston, MA, November 1995.

Lin, Z.-C. (with Inn, K.G.W. and Crespo, C.E.), "Determination of Trace Concentrations of Actinides in the NIST Bone Ash Standard Reference Materials Using TRU-Spec Extraction Resin," 41st Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Boston, MA, November 1995.

Lin, Z.-C. (with Inn, K.G.W. and Crespo, C.E.), "Determination of The Low-Level Radioactivity Ocean Sediment Standard Reference Material," 4th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, Gaithersburg, MD, November 1995.

Lin, Z.-C. (with Thomas, J., Inn, K.G.W., Sleeman, R.E., and Bakhtiar, S.N.), "Gravimetric Yield by Constant Mass?" 42nd Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, San Francisco, CA, November 1996.

McLaughlin, W.L., "Retrospective Assessment of Radiation Overexposure Using Tooth Enamel," University of Texas, El Paso, TX, March 1995.

McLaughlin, W.L., "Pulse Radiolysis and Radiation and Radiation Chemical Kinetics of Radiochromic Sensors," Hungarian Academy of Sciences Seminar, Institute of Isotopes, Budapest, Hungary, March 1995.

McLaughlin, W.L., "Photofluorescent High-Dose Electron Beam Measurements Using Wave-Shifted, Blue- and Green-Emitting Doped Polymers," Hungarian Academy of Sciences Seminar, Budapest, Hungary, March 1995.

McLaughlin, W.L., "Development of Calorimetric Standards for Calibration of High-Dose Electron Beam Dosimeters," International Atomic Energy Agency Coordinated Meeting on Quality Control of Electron Beam Processing, Risø National Laboratory, Roskilde, Denmark, April 1995.

McLaughlin, W.L., "Colour Centers in LiF for Measurement of Absorbed Doses Up to 100 MGy," 11th International Conference on Solid State Dosimetry, Budapest, Hungary, July 1995.

McLaughlin, W.L., "The Effect of Formulation Properties on the Response to Ionizing Radiation of Radiochromic Dye Films," 11th International Conference on Solid State Dosimetry, Budapest, Hungary, July 1995.

McLaughlin, W.L., "Calibration of GafChromic Dosimeters," 11th International Conference on Solid State Dosimetry, Budapest, Hungary, July 1995.

McLaughlin, W.L., "A Novel Radiochromic film for Clinical Dosimetry," 11th International Conference on Solid State Dosimetry, Budapest, Hungary, July 1995.

McLaughlin, W.L., "Environmental Effects in High-Dose Dosimetry," Third International Workshop on Dosimetry for Radiation Processing, Ste-Adele, Quebec, Canada, October 1995.

McLaughlin, W.L., "Basic Principles of Radiation Interactions and Dosimetry," Third International Workshop on Dosimetry for Radiation Processing, Ste-Adele, Quebec, Canada, October 1995.

McLaughlin, W.L., "Food Irradiation Dosimetry," American Nuclear Society, Washington, DC, November 1995.

McLaughlin, W.L., "Fluorescent Polymers for Radiographic Imaging and Dosimetry," Zoltan Bay Institute, Hungarian Academy of Sciences, Budapest, Hungary, October 1996.

O'Brien, C.M., "The Development of a National Standard for Mammographic Beam Qualities," American Association of Physicist in Medicine, Boston, MA, June 1995.

Schultz, M. (with Burnett, W.C., Inn, K.G.W., Thomas, J.W.L. and Lin, Z.-C.), "Development of a Sequential Extraction Technique to Define the Fractionation of Radioactive Elements in NIST Natural Matrix Standards," Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Boston, MA, November 1995.

Seltzer, S.M., "Physics of ETRAN and ITS Electron-Photon Monte Carlo Codes," American Nuclear Society, San Francisco, CA, October 1995.

Seltzer, S.M., "Version 4.0 of ITS Electron/Photon Monte Carlo Transport Codes," American Nuclear Society, San Francisco, CA, October 1995.

Shobe, J., "The Expression of Uncertainty for Metrology," Harshaw TLD User Group Meeting, Las Vegas, NV, March 1995.

Shobe, J., "Status of ANSI N13.29 and N13.37," Harshaw TLD User Group Meeting, Las Vegas, NV, March 1995.

Shobe, J., "The Expression of Uncertainty for Metrology," Panasonic TLD User Symposium, Seven Springs, PA, June 1995.

Shobe, J., "Development of a Quality Manual for Secondary Calibration Laboratories – Uncertainty Analysis," Health Physics Society, Boston, MA, July 1995.

Soares, C.G., "Ionizing Radiation for the Treatment of Heart Disease: A New Frontier for Dosimetry," NIST Physics Laboratory Colloquium, Gaithersburg, MD, February 1996.

Soares, C.G., "Hot Particles for Heart Disease?!" Northern New Jersey Chapters of the American Nuclear Society and the Health Physics Society, Somerset, NJ, March 1996.

Soares, C.G., "Surface and Near Surface Absorbed-Dose Measurements of Beta-Particle Emitters," University of Wisconsin, Madison, WI, April 1996.

Soares, C.G., "Dosimetry of Radiation for Restenosis," American Association of Physicists in Medicine, College Park, MD, June 1996.

Soares, C.G., "Characteristics of Scanning Densitometers for High-Resolution Readout of Radiochromic Film," American Association of Physicists in Medicine, Philadelphia, PA, July 1996.

Soares, C.G., "Calibration and Characterization of Beta-Particle Sources for Intravascular Brachytherapy," American Association of Physicists in Medicine, Philadelphia, PA, July 1996.

Soares, C.G., "Standards for Brachytherapy at NIST," National Research Council of Canada, November 1996.

Spadanuta, J. (with Lin, Z.-C. and Inn, K.G.W.), "Solubility Distribution of Thorium in Columbia River Sediment (SRM 4350B)," 42nd Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, San Francisco, CA, November 1996.

Thomas, J.W.L. (with Inn, K.G.W., Garcia, M.E. and Martinez, R.), "Speciation of ^{90}Sr in NIST Natural Matrix Standard Reference Materials," Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Boston, MA, November 1995.

Thomas, J.W.L. (with Inn, K.G.W., Garcia, M.E., and Martinez, R.), "Speciation of ^{90}Sr in NIST Natural Matrix Standard Reference Materials," 4th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, Gaithersburg, MD, November 1995.

Thompson, A.K., "Three Methods to Polarize ^{3}He," European Research Conference: Polarization in Electron Scattering, Santorini, Greece, September 1995.

Unterweger, M.P., "RADIAC Working Group," Defense Nuclear Agency, Alexandria, VA, October 1995.

Walker, M.L., "Radiation Processing - Practical Applications of Radiation Physics and Chemistry," National Society of Black Physicists, Atlanta, GA, April 1995.

Walker, M.L., "Optical Means of Remote Dose Determination," National Organization for the Professional Advancement of Black Chemists and Chemical Engineers, Los Angeles, CA, April 1995.

Wietfeldt, F.E., "A Search for Time-Reversal Violation in Polarized Neutron Decay," Lawrence Livermore National Laboratory, Livermore, CA, June 1995.

Wietfeldt, F.E., "A Search for Time-Reversal Violation in Polarized Neutron Decay," University of Maryland, College Park, MD, December 1995.

Wietfeldt, F.E., "Fundamental Research with Polarized Neutrons at NIST," Los Alamos National Laboratory, Los Alamos, NM, June 1996.

Zimmerman, B.E. (with Collé, R.), "The Standardization of ^{63}Ni by Liquid Scintillation Spectrometry with ^{3}H- Standard Efficiency Tracing: A New Calibration and Review of Data from Calibrations over the Past 27 Years," 4th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, Gaithersburg, MD, November 1995.

Zimmerman, B.E., "Radioactivity Standards for Nuclear Medicine: Overview of the NIST/NEI Program Report of Recent Results," University of Missouri Research Reactor Facility, Columbia, MO, May 1996.

Zimmerman, B.E. (with Cessna, J.T., and Schima, F.J.), "The Calibration of the Potential Bone Palliation Radiopharmaceutical ^{117m}Sn(IV)DTPA," 38th Annual Meeting of the American Association of Physicists in Medicine, Philadelphia, PA, July 1996.

Zimmerman, B.E., "Development of Standards for New Radiopharmaceuticals," Nuclear Energy Institute Radiopharmaceutical Steering Committee Meeting, Washington, DC, October 1996.
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TIME AND FREQUENCY DIVISION (847)

Bergquist, J.C., "Laser-cooled Hg^+ ions for accurate microwave and optical clocks," 1996 Joint Meeting of the American Physical Society and the American Association of Physics Teachers, Indianapolis, IN, May 1996.

Bergquist, J.C., "Quantum physics and frequency standards with single stored ions," Oregon State University, May 1996.

Bergquist, J.C., "Stable cavities and optical frequency standards," NASA Workshop, Rochester, NY, October 1996.

Bollinger, J.J., "Spin Squeezing: Beating the Quantum Limit in Spectroscopy," Colorado State University, Fort Collins, CO, March 1995.

Bollinger, J.J., "Bragg Scattering from Laser-cooled Ions in a Penning Trap," DAMOP annual meeting of the American Physical Society, University of Toronto, Toronto, Canada, May 1995.

Bollinger, J.J., "Observation of long-range order in trapped ion plasmas by Bragg scattering," International Conference on the Physics of Strongly Coupled Plasmas, Binz, Germany, September 1995.

Bollinger, J.J., "Spin-squeezing applied to frequency standards," Fifth Symposium on Frequency Standards and Metrology, Woods Hole, Mass., October 1995.

Bollinger, J.J., "Observation of long-range order in laser-cooled, trapped ion plasmas by Bragg scattering," 37th American Physical Society Division of Plasma Physics meeting, Louisville, KY, November 1995.

Bollinger, J.J., "Experiments with Trapped Ions: Observation of Crystals by Bragg Scattering and Ideas for Generating Correlated Atomic States," University of Texas, Austin, TX, December 1995.

Bollinger, J.J., "Ion Trap Atomic Clocks," University of Texas, Austin, TX, December 1995.

Bollinger, J.J., "Observation of pure ion (Wigner) crystals (no electrons!)," Rice University, Houston, TX, January 1996.

Bollinger, J.J., "Observation of pure ion (Wigner) crystals (no electrons!)," APAS plasma seminar, University of CO, April 1996.

Bollinger, J.J., "Observation of ion crystals in a Penning trap by Bragg Scattering," University of California at San Diego, CA, April 1996.

Bollinger, J.J., "Optimum frequency measurements with maximally correlated states," Indianapolis, IN, May 1996.

Bollinger, J.J., "Experiments with correlated trapped ion plasmas," Symposium in honor of John Schiffer, Argonne, IL, May 1996.

Drullinger, R.E., "Quantum Mechanical Oscillators: NIST-7 and Beyond," American Physical Society, St. Louis, MO, March 1996.

Drullinger, R.E., "The evaluation of NIST-7, A new era," Braunschweig, Germany, June 1996.

Drullinger, R.E., "A series of lectures on atomic clocks to be given at the "Time and Frequency Seminar '96," National Center of Metrology of Mexico, in Queretaro, Mexico, October 1996.

Drullinger, R.E., "NIST-7, the US Primary Frequency Standard," Twenty-eighth Annual Precise Time and Time Interval Meeting, Reston, VA, December 1996.

Evenson, K.M., "Improved molecular constants from frequency measurements of many bands of the fluorescence-stabilized CO_2 and N_2O lasers," 14th Colloquium on High Resolution Molecular Spectroscopy, Institute for Molecular Science, Okazaki, Japan, March 1995.

Evenson, K.M., "Improved molecular constants from frequency measurements of many bands of the fluorescence-stabilized CO_2 and N_2O lasers," 14th Colloquium on High Resolution Molecular Spectroscopy, Dijon, France, September 1995.

Evenson, K.M., "Laser frequency spectroscopy: A review," Molecular Spectroscopy Seminar, Columbus, OH, June 1996,

Evenson, K.M., "$^{13}CH_3OH$ far infrared laser: newly discovered lines, predictions and assignments," International Society for Optical Engineering, Denver, CO, August 1996.

Evenson, K.M., "Metrology with IR gas lasers: Frequency measurements of fluorescence-stabilized CO_2 and N_2O lasers," IEEE Lasers and Electro Optics Society, Boston, MA, November 1996.

Fox, R., "Active control of am and fm noise suppression," Society of Photo-optical instrumentation Engineers (SPIE) conference, San Jose, CA, February 1995.

Fox, R., "Extending the wavelength coverage of diode lasers," Optical Society of America Conference on Environmental Analysis, Orlando FL, March 1996.

Hollberg, L., "Diode lasers filling in the gaps," Winter colloquium on quantum electronics," Snowbird, UT, January 1995.

Hollberg, L., "FM and am noise conversion by atomic resonances," Society of Photo-optical instrumentation Engineers (SPIE) conference, San Jose, CA, February 1995.

Hollberg, L., "Lasing without inversion in Rb," International conference on Quantum Electronics/CLEO/QELS/IQEC," Baltimore, MD, May 1995.

Hollberg, L., "Diode lasers for frequency standards and precision spectroscopy," Frequency Control Symposium, San Francisco, CA, May 1995.

Hollberg, L., "Coherence effects, Lasing without inversion and Raman oscillations in Rb," Twelfth International Conference on Laser Spectroscopy, Isle of Capri, Italy, June 1995.

Hollberg, L., "Precision Measurements with diode lasers," 1995 Optical Society of America annual meeting/ILS-XI, September 1995.

Hollberg, L., "Nonlinear optics with diode laser for optical frequency measurements," Symposium on frequency standards and metrology, Woods Hole, MA, October 1995.

Hollberg, L., "Diode lasers and Spectroscopy," IEEE/LEOS Conference, San Francisco, CA, October 1995.

Hollberg, L., "Lasing without population inversion," University of Colorado, Denver, CO, November 1995.

Hollberg, L., "Diode lasers for spectroscopy from the UV to the far IR", 43rd Annual Western Spectroscopy Association Conference, January 1996.

Hollberg, L., "Lasing without population inversion and other coherence effects," Colorado State University, Fort Collins, CO, April 1996.

Hollberg, L., "Atomic Physics with semiconductor lasers," Texas A&M, College Station, TX, May 1996.

Hollberg, L., "Semiconductor lasers for spectroscopy from the UV to the Far IR," Molecular Spectroscopy Seminar, Columbus, OH, June 1996.

Hollberg, L., "Experiments on laser oscillation without inversion," European Conference on Lasers and Electro-Optics/European Quantum Electronics Conference, Hamburg, Germany, September 1996.

Hollberg, L., "Diode laser applications and coherence effects in multi-level atoms," European Laboratory of Nonlinear Spectroscopy, Florence, Italy, September 1996.

Howe, D., "Characterization of clocks and oscillators," Measurement Science Conference, Anaheim, CA, January 1996.

Howe, D., "The effects of drift on total deviation," Frequency Control Symposium, June 1996.

Itano, W.M., "High-magnetic-field perturbations to the cesium hyperfine structure," Frequency Standards and Metrology Symposium, Woods Hole, MA, October 1995.

Itano, W.M., "Bragg scattering of laser light from trapped-ion crystals," Atomic Physics Division Seminar, NIST, Gaithersburg, MD, February 1996.

Jefferts, S., "Time Transfer Technology," Taiwan Institute of Telecommunications Laboratory, Taipei, Taiwan, June 1995.

Jefferts, S., "GPS Cs Clocks - present and future," University of Raleigh/Durham, NC, August 1995.

Jefferts, S., "Classical squeezing of quartz oscillators," Frequency Control Symposium, Woods Hole, MA, October 1995.

Jefferts, S., "Two-way time transfer through SDH and SONET systems," European Frequency and Time Forum, Brighton, UK, March 1996.

Jefferts, S., "Two-way time transfer in SONET systems," Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 1996,

King, B., "Schrodinger's cat with an atom," University of Texas, Arlington, TX, October 1996.

Kitching, J., "A 1GHz optical delay line oscillator driven by a diode laser," Frequency Control Symposium, Honolulu, HI, June 1996.

Lee, D., "An atomic beam velocity servo for optically pumped frequency standards," IEEE Frequency Control Symposium, Honolulu, HI, June 1996.

Lee, D., "Recent advances in primary frequency standards," National Conference of Standards Laboratories," Monterey, CA, August 1996.

Levine, J., "Authentication of time signals," and "Delivering real-time," Precise Time and Time Interval Conference, San Diego, CA, November 1995.

Meekhof, D., "Resolved sideband raman cooling of a bound atom to the zero-point energy," Division of Atomic Molecular Optical Physics Conference, Toronto, Ontario, Canada, May 1995.

Meekhof, D., "Non-classical states of motion of a trapped ion," Optical Society of America Conference, Portland, OR, September 1995.

Meekhof, D., "Quantum computation," Williams College, Albany NY, April 1996.

Meekhof, D., "Generation of nonclassical states of motion," University of Oregon, Eugene, OR, May 1996.

Meekhof, D., "Generation of nonclassical motional states of a trapped ion," DAMOP, Ann Arbor, MI, May 1996.

Meekhof, D., "Generation of nonclassical states of motion of a trapped ion," Optics and Interferometry with Atoms Workshop, Elba, Italy, June 1996.

Meekhof, D., "Generation of nonclassical motional states of a trapped ion," Optical Society of America, Rochester, NY, October 1996.

Miller, J., "Cryogenic linear trap for accurate spectroscopy," Division of Atomic Molecular Optical Physics Conference, Toronto, Ontario, Canada, May 1995.

Monroe, C., "Quantum mechanically correlated states and atomic clocks," Moriand Workshop on atomic clocks," Villars-sur-Ollon, Switzerland, January 1995.

Monroe, C., "Nonclassical states of a trapped ion," University of Connecticut, Storrs, CT, February 1995.

Monroe, C., "Quantum logic with trapped ions," IBM T.J. Watson Laboratory, Yorktown Heights, NY, February 1995.

Monroe, C., "Quantum logic with trapped ions," California Institute of Technology, Pasadena, CA, March 1995.

Monroe, C., "Coherent Control of the vibrational states of a trapped ion," American Chemical Society, Anaheim, CA, April 1995.

Monroe, C., "Quantum optics with a trapped ion laser-cooled to the zero-point energy," University of Rochester on Quantum Optics, Rochester, NY, June 1995.

Monroe, C., "New experiments with trapped ions," 12th International Conference on Laser Spectroscopy," Isle of Capri, Italy, June 1995.

Monroe, C., "Cooling a bound atom to the zero-point energy and more," Optical Society of America annual meeting, Portland OR, September 1995.

Monroe, C., "Nonclassical states of a trapped ion," J. Sweica School for Quantum Optics, Rio de Janeiro, Brazil, January 1996.

Monroe, C., "Quantum computation with trapped ions," University of Colorado, Boulder, CO, February 1996.

Monroe, C., "Quantum computation with trapped ions," University of Oregon, Eugene, OR, April 1996.

Monroe, C., "From quantum gates to quantum computers with trapped ions," DAMOP, Ann Arbor, MI, May 1996.

Monroe, C., "Quantum logic gates with trapped ions," Quantum Computation at UCSB Institute for Theoretical Physics, University of California, Santa Barbara, CA August 1996.

Monroe, C., "Quantum computers and Schrödinger's cat," European Science Foundation Conference, Pisa, Italy, September 1996.

Monroe, C., "Quantum computers and Schrödinger's cat," University of Wyoming, Laramie, WY, September 1996.

Monroe, C., "Quantum computers and Schrödinger's cats, "University of Illinois, Urbana-Champaign, IL, October 1996.

Monroe, C., "Schrödinger cats and quantum computers," University of Florida, Gainesville, FL, October 1996.

Monroe, C., "Schrödinger cats and quantum computers," Massachusetts Institute of Technology, Boston, MA, October 1996.

Monroe, C., "Quantum computers and Schrödinger's cat," Northwestern University, Chicago, IL, November 1996.

Nelson, L., "Recent improvements made to the NIST frequency measurement service," National Conference of Standards Laboratories, Dallas, TX, July 1995.

Parker, T., "Time and Frequency Transfer (state-of-the-art and traditional)," Frequency Control Symposium, San Francisco, CA, June 1995.

Parker, T., "Noise analysis of non-equally spaced TWSTFT data," Precise Time and Time Interval Conference, San Diego, CA, November 1995.

Parker, T., "Recent improvements in the performance of the NIST AT1 time scale," IEEE Frequency Control Symposium, Honolulu, HI, June 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer International Symposium on Acoustoelectronics, Moscow, Russia, September 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer Tele Quartz, Heidelberg, Germany, September 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer Institute of Solid State Physics, Sophia, Bulgaria, September 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer C-MAC Quartz Crystals Ltd., Harlow, UK, September 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer Marquette University, Milwaukee, WI, October 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer 17th Symposium on Ultrasonic Electronics, Yonezuwa, Japan, October 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer NEC, Yokohama, Japan, October 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer Toyo Tusinki Co., Yonezawa, Japan, October 1996.

Parker, T., "The search for the perfect oscillator," IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Distinguished Lecturer Murata Co, Kyoto, Japan, Japan, October 1996.

Parker, T., "The search for the perfect oscillator," Tokyo Chapter of the IEEE Society on Ultrasonics, Ferroelectrics, and Frequency Control, Tokyo, Japan, October 1996.

Stephens, M., "Optimizing captive efficiency in a magneto-optical trap," SPIE International Symposium on Lasers and Applications, San Jose, CA, February 1995.

Sullivan, D.B., "Timekeeping: Synch or Swim,: Cosmos Club, Washington, DC, April 1995.

Sullivan, D.B., "Time Generation and Distribution,: Telecommunications Laboratory, Chung-Li, Taiwan, October 1995.

Sullivan, D.B., "Time and Frequency Metrology," International Conference on Advances in Metrology and its role in Quality Improvement and Global Trade," New Delhi, India, February 1996.

Tan, J., "Bragg scattering from stored ions," University of Nevada, Las Vegas, NV, April 1995.

Tan, J., "Bragg scattering probe of long-range order in stored ions," Gordon Conference, Wolfeboro, NH, July 1995.

Tan, J., "Minimizing time-dilation in a stored ion clock," Frequency Standards and Metrology Symposium, Woods Hole, MA, October 1995.

Walls, F., "Reducing noise in electronics for precision frequency metrology," Frequency Standards and Metrology Symposium, Woods Hole, MA, October 1995.

Walls, F., "A standard for PM and AM noise at 10.6, 21.2, and 42.4 GHz," Frequency Control Symposium, Honolulu, HI , June 1996.

Weiss, M., "NIST suggestions for improving GPS," GPS performance analysis working group, Colorado Springs, CO, August 1995.

Weiss, M., "Intro to Time and Frequency statistics," PTTI, Reston, VA, November 1996.

Wineland, D.J., "Entangled states for spectroscopy and computation," University of Washington, Seattle, WA, March 1995.

Wineland, D.J., "Entangled states for spectroscopy and computation," Massachusetts Institute of Technology, Cambridge, MA, May 1995.

Wineland, D.J., "Entangled states for spectroscopy and computation," Gordon Conference on Atomic Physics, Wolfeboro, NH, July 1995.

Wineland, D.J., "Quantum logic with trapped ions," Advanced Research Project Agency, Washington DC, September 1995.

Wineland, D.J., "Laser cooling of stored ions," Frequency Standards and Metrology Symposium, Woods Hole, MA, October 1995.

Wineland, D.J., "Application of laser-cooled ions to frequency standards and metrology," Fifth Symposium Frequency Standards and Metrology, Woods Hole, MA, October 1995.

Wineland, D., "Entangled states for spectroscopy and computation," Harvard University, Cambridge, MA, February 1996.

Wineland, D., "Single atom clocks," Boise State University, Boise, ID, March 1996.

Wineland, D., "Single atom clocks," University of St. Louis, St. Louis, MO, April 1996,

Wineland, D., "Entangled states for spectroscopy and computation," University of New Mexico, Albuquerque, NM, April 1996.

Wineland, D., "Entangled states for spectroscopy and computation," University of Rochester, Rochester, NY, May 1996.

Wineland, D., "Nonclassical motional states of trapped atoms," Symposium on trends in atomic physics, Gothenburg, Sweden, May 1996.

Wineland, D.J., "Entangled states for spectroscopy and computation," ITP Conference on quantum coherence and decoherence, University of California, Santa Barbara, CA, June 1996.

Wineland, D.J. "Nonclassical motional states of a trapped atom," Quantum Electronics and Laser Science (QELS), Anaheim, CA, June 1996.

Wineland, D.J. "NIST project on trapped-ion quantum logic," ARPA/NSA workshop on quantum computation, Bowie, MD, July 1996.

Wineland, D.J. "Entangled states for spectroscopy and computation," Defense Science Research Council Workshop, La Jolla, CA, July 1996.

Wineland, D.J. "Entangled states of atomic ions for quantum metrology and computation," International Conference on Atomic Physics (ICAP), Amsterdam, Netherlands, August 1996.

Wineland, D.J. "Schrödinger's cat, quantum computation, and atomic clocks," NIST colloquium, Gaithersburg, August 1996.

Wineland, D.J. "Schrödinger's cat, quantum computation, and atomic clocks," Boulder, CO, August 1996.

Wineland, D.J., "Entangled states and quantum logic with trapped ions," Optical Society of America, Rochester, NY, October 1996.

Wineland, D., "Trapped ions, Schrödinger's cat, and quantum logic," University of Maryland, MD, October 1996.

Wineland, D.J., "Entangled states of trapped atoms," LASERS '96, Portland, OR, December 1996. ▫

QUANTUM PHYSICS DIVISION (848)

Bender, P.L., "Overview of Space Based Gravitational Wave Detectors," at Aspen Winter Conference on Gravitational Waves and their Detection, Aspen, Colorado, January 1995.

Bender, P.L., "Symposium on Space Borne Interferometry II," SPIE (International Society for Optical Engineering) Conference, Kissimmee, FL, April 1995.

Bender, P.L., "Determination of a Mercurian Liquid Core," at Workshop on Mercury and Its Magnetosphere, London, UK, May 1995.

Bender, P.L., "LISA Overview and Target Sources for LISA," at Penn State Conference on Astrophysical Sources of Gravitational Waves, University Park, Pennsylvania, July 1995.

Clement, T.S., "Characterization of Ultrafast Interactions with Materials through the Direct Measurement of the Optical Phase," SPIE, OE/LASE '96, San Jose, CA, January 1996.

Cornell, E.A., "Developments in Cooling and Manipulating Atoms and More Complicated Objects," American Chemical Society meeting, Anaheim, CA, April 1995.

Cornell, E.A. "Evaporative and Cyclic Cooling: Colder Magnetically Trapped Atoms at JILA," American Physical Society DAMOP meeting, Toronto, Canada, May 1995.

Cornell, E.A. "Evidence for Bose-Einstein Condensation in Rb-87," Twelfth International Conference on Laser Spectroscopy, Capri, France, June 1995.

Cornell, E.A. "Observation of BEC in Rb-87," BEC-II, Strasbourg, France, June 1995.

Cornell, E.A. "BEC," Gordon Conference on Atomic Physics, Wolfeboro, NH, July 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute vapor," Aspen Center for Physics, Aspen, CO, August 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Vapor," Massachusetts Institute of Technology, Cambridge, MA, September 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Vapor," University of Colorado, Boulder, CO, September 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Vapor," Colorado State University, Fort Collins, CO, September 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Vapor," University of Connecticut, Storrs, CT, September 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Vapor," University of Illinois, Urbana, IL, October 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Vapor," University of California, Berkeley, CA, November 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Vapor," Stanford University, Palo Alto, CA, November 1995.

Cornell, E.A., "Weird Quantum Gas: Einstein comes to Boulder," Gamow Memorial Lecture, Boulder, CO, November 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Vapor," Chemical Physics Seminar, University of Colorado, Boulder, CO, December 1995.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," Harvey Mudd College, Ontario, CA, January 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," University of Riverside, Riverside, CA, January 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," California Institute of Technology, Pasadena, CA, February 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," Stanford Laser Acceleration Center, Palo Alto, CA, February 1996.

Cornell, E.A., "Very Cold Indeed: the Nanokelvin Physics of BEC," NIST Colloquium Series, NIST, Gaithersburg, MD, February 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," University of Virginia, Charlottesville, VA, February 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," University of Maryland, College Park, MD, February 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," University of New Mexico, Albuquerque, NM, March 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," Scuole Normale Superiore, Pisa, Italy, March 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," Max Planck Institute, Garching, Germany, March 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," German Physical Society, Rostock, Germany, March 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," 1996 Manne Siegbahn Memorial Lecture, Manne Siegbahn Laboratory, Stockholm, Sweden, March 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," Workshop on Collective Effects in Ultracold Gases, Les Houches, France, April 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," International Quantum Electronics Conference, Sydney, Australia, July 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," meeting of the Optical Society of America, Rochester, NY, October 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," Symposium of the National Academy of Sciences, Irvine, CA, October 1996.

Cornell, E.A., "Bose-Einstein Condensation in a Dilute Atomic Gas," XXth International Workshop on Condensed Matter Theories, Pune, India, December 1996.

Dunn, G.H., "The New Faces of Electron-Ion Collisions," Annual Meeting of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society (DAMOP), Toronto, Canada, May 1995.

Dunn, G.H., "Atomic Collisions," Tenth Topical Conference on Atomic Processes in Plasmas, San Francisco, CA, January 1996.

Dunn, G.H., "Compound State Effects in Selected Atomic Collisions," University of Nevada, Reno, March 1996.

Faller, J.E., "Issues for LIGO's User Community," Aspen, CO, January 1995.

Faller, J.E., "The Physics of Sports," The University of Glasgow, Glasgow, Scotland, August 1995.

Faller, J.E., "Precision Measurements with Gravity," American Physical Society Spring Meeting, Indianapolis, IN, May 1996.

Faller, J.E., "Physics of Basketball," two talks at Steamboat Springs Middle School, Steamboat Springs, CO, May 1996.

Faller, J.E., "The Measurements of G," Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 1996.

Faller, J.E., "The Measurements of G: A New Free-Fall Approach," University of Glasgow, August 1996.

Faller, J.E., "The Measurements of g," The Finnish Geodetic Institute, August 1996.

Faller, J.E., "The Measurements of g and G," University of Technology, University of Helsinki, August 1996.

Faller, J.E., "The Current States of Absolute Gravimetry and Some Ideas and Suggestions for Future Improvements," International Symposium on Gravity, Geoid and Marine Geodesy, Tokyo, Japan, September 1996.

Gallagher, A.C., "Continuous Small Particle Deposition From a Silane rf Discharge," Dusty Plasmas 95 Conference, Phoenix, AZ, September/October 1995.

Gallagher, A.C., "Self Focusing and Cone Emission," 13th International Conference on Line Shapes, Firenze, Italy, June 1996.

Gallagher, A.C., "STM Studies of a-Si-H, Powder Formation," 7th NREL a-Si Guidance and Technical Team Meeting, Breckenridge, CO, August 1996.

Hall, J.L., "Stability and Absolute Frequency of Molecular Iodine Transition Near 532 nm," Photonics West SPIE, San Jose, CA, February 1995.

Hall, J.L., "Improved Optical Frequency Measurements and Standards," Laser Spectroscopy XII, Capri, Italy, June 1995.

Hall, J.L., "Advances in Stabilized Lasers With Applications in Fundamental Physics," Special Seminar on Atom Cooling and Manipulation, Tokyo, Japan, August 1995.

Hall, J.L., "Visible Molecular Overtone Transitions – Thousands of New Wavelength References," Massachusetts Institute of Technology, Laser Spectroscopy Seminar Series, October 1995.

Hall, J.L., "Optical Frequency Standards," Fifth Symposium on Frequency Standards and Metrology, Woodshole, MA, October 1995.

Hall, J.L., "Advances in Optical Frequency Measurement and Stabilization," Institute for Laser Science, University of Electro-Communications, March 1996.

Hall, J.L., "Using Precise Optical Frequency Measurement for Physics," Symposium on Modern Spectroscopy, Université de Paris, March 1996.

Hall, J.L., "Using Precise Optical Frequency Measurement for Physics," University of New Mexico, Albuquerque, NM, April 1996.

Hall, J.L., "Towards the Ultimate Detections Sensitivity in Optical Spectroscopy: Zillons of New Wavelength Standards Based on Molecular Overtones," International Symposium on Molecular Spectroscopy, Ohio State University, Columbus, OH, June 1996.

Hall, J.L., "Precision Measurement of the Natural Lifetime of NA Using Frequency-Domain Spectroscopy of Ultracold Atoms," International Conference on Quantum Electronics, Sydney, Australia, July 1996.

Hall, J.L., "Stabilization of Commercial Tunable Lasers at the Sub-Hertz Level," Conference on Optical Science and Laser Technology, Montana State University, Bozeman, MT, September 1996.

Jin, D., "Bose-Einstein Condensation in a Dilute Vapor," Division of Atomic Molecular and Optical Physics Meeting, Ann Arbor, MI, May 1996.

Jin, D., "Bose-Einstein Condensation in a Dilute Vapor," XXI International Conference on Low Temperature Physics, Prague, Czech Republic, August 1996.

Leone, S.R., "Laser Probing of Stereochemical Effects," University of Puerto Rico, Rio Piedras, Puerto Rico, February 1995.

Leone, S.R., "Laser Ionization Flux Monitoring during GaAs Growth," Symposium on Monitoring and Control Techniques for Intelligent Epitaxy, Banff, Alberta, Canada, June 1995.

Leone, S.R., "Introduction to the Session on Ion-molecule and Rydberg Dynamics," 1995 Conference on the Dynamics of Molecular Collisions, Asilomar, CA, July 1995.

Leone, S.R., "Sterochemical Effects in Collision Dynamics," 1995 Bourke Lectures, Faraday Divisional Council, Edinburgh, Birmingham and Southampton, UK, October 1995.

Leone, S.R., "Sterochemical Effects in Collision Dynamics," Oxford University, UK, October 1995.

Leone, S.R., "Sterochemical Effects in Collision Dynamics," Cambridge University, UK, October 1995.

Leone, S.R., "Sterochemical Effects in Collision Dynamics," University of Leeds, UK, October 1995.

Leone, S.R., "Sterochemical Effects in Collision Dynamics," University College London, UK, October 1995.

Leone, S.R., "Laser Probing of Epitaxy and Etching," Colorado School of Mines Physics Colloquium, Golden, CO, November 1995.

Leone, S.R., "Laser Probing of Epitaxy and Etching," University of California, Berkeley, CA, December 1995.

Leone, S.R., "Laser Studies of Epitaxy and Etching," University of Mainz, Mainz, Germany, January 1996.

Leone, S.R., "Laser Studies of Epitaxy and Etching," University of Wurzburg, Wurzburg, Germany, January 1996.

Leone, S.R., "Laser Studies of Epitaxy and Etching," University of Freiburg, Freiburg, Germany, January 1996.

Leone, S.R., "Reactions and Photofragmentation of Doubly Charged Molecular Ions: Novel Pathways, Structure, and Energy Thresholds," Symposium on Atomic, Cluster and Surface Physics, Engelberg, Switzerland, January 1996.

Leone, S.R., "Laser Probing of Epitaxy and Etching," University of Utah, Salt Lake City, UT, March 1996.

Leone, S.R., "Laser Studies of Sterochemical Effects," University of Wisconsin, Eau Claire, WI, March 1996.

Leone, S.R., "Ultrafast Wave Packet Dynamics with Intermediate State Control," Gordon Conference on Multiphoton Processing, Colby-Sawyer College, New London, NH, June 1996.

Leone, S.R., "Ultrafast wave Packet Dynamics with Intermediate State Control," Informal Photochemistry Conference, Minneapolis, MN, June 1996.

Leone, S.R., Laser Science Division of the American Physical Society Undergraduate College Traveling Distinguished Lecturer, Lecture Series on Lasers at University of Wisconsin, Oshkosh, October 1996.

Leone, S.R., "Time-Resolved Fourier Transform Infrared Emission Studies of Atom-Molecule Collisions," Optical Society of America, 12th Interdisciplinary Laser Science Conference, Rochester, NY, October 1996.

Leone, S.R., "Alignment and Control of Rovibronic Wave Packets," Free University of Amsterdam, Amsterdam, October 1996.

Leone, S.R., "Chemical Dynamics of Alignment and Control," University of California at San Diego, La Jolla, CA, November 1996.

Leone, S.R., "Chemical Dynamics of Alignment and Control," University of California at Los Angeles, CA, November 1996.

Leone, S.R., "Chemical Dynamics of Alignment and Control," University of Southern California, Los Angeles, CA, November 1996.

Leone, S.R., "Chemical Dynamics of Alignment and Control," California Institute of Technology, Pasadena, CA, November 1996.

Linsky, J.L., "What Hubble is Telling us About Stellar Magnetic Activity and the Lowest Mass Stars," Goddard Space Flight Center, Greenbelt, MD, February 1995.

Linsky, J.L., "What Hubble is Telling us About Stellar Magnetic Activity and the Lowest Mass Stars," State University of New York, Stony Brook, NY, February 1995.

Linsky, J.L., "Chromospheres of Coronal Stars," International Astronomical Union Symposium No. 153 -- Phenomena in the Solar Atmosphere: Prototypes of Stellar Magnetic Activity, Tokyo, Japan, May 1995.

Linsky, J.L., "Deuterium," Aspen Workshop on Big Bang Nucleosynthesis, Aspen, CO, June 1995.

Linsky, J.L., "Steady Radio Emission from Stars: Observations and Emission Processes," Workshop on Radio Emission from the Sun and Stars, Barcelona, Spain, July 1995.

Linsky, J.L., "Analysis of the Alpha Centauri Line of Sight: Properties of Local Interstellar Gas, and Detection of Heated Hydrogen Near the Heliopause," High Altitude Observatory, Boulder, CO, September 1995.

Linsky, J.L., "Summary of IAU Symposium 176," IAU Symposium No. 176 -- Stellar Surface Structure, Vienna, Austria, October 1995.

Linsky, J.L., "Summary of Cool Stars 9," Ninth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, Florence, Italy, October 1995.

Linsky, J.L., "GHRS Studies of Stellar Chromospheres, Transition Regions, and Coronae," Ninth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, Florence, Italy, October 1995.

Linsky, J.L., "HST Observations of the Local Interstellar Medium," ISSI Workshop -- The Heliosphere in the Local Interstellar Medium, Bern, Switzerland, November 1995.

Nesbitt, D.J., "Injection Seeded Optical Parametric Oscillators: Vibrationally Mediated Photodissociation from Pure Quantum States," University of Adelaide, Adelaide, Australia, February 1995.

Nesbitt, D.J., "Full and Half Collision Dynamics with Quantum State Selected 'Reagents'." Macquarie University, Sydney, Australia, February 1995.

Nesbitt, D.J., "Full and Half Collision Dynamics with Quantum State Selected 'Reagents'." Australian Conference on Physical Chemistry and Sixth Australian Conference on Chemical Reaction Dynamics, Canberra, Australia, February 1995.

Nesbitt, D.J., "State-to-State Dynamics and Intermolecular Potentials: Insights from High Near-IR Resolution Laser Methods," University of California, Berkeley, CA, May 1995.

Nesbitt, D.J., "State-to-State Dynamics and Intermolecular Potentials: Insights from High Near-IR Resolution Laser Methods," California Institute of Technology, Pasadena, CA, May 1995.

Nesbitt, D.J., "High Resolution IR Laser Studies of Molecular Clusters: Walking the Line Between Spectroscopy and Dynamics," Columbus, OH, June 1995.

Nesbitt, D.J., "Open and Closed Shell Inelastic Collisions," CCP6 Workshop on Inelastic Collisions and Dynamics in the Atmosphere, Durham, UK, July 1995.

Nesbitt, D.J., "IR-UV Double Resonance Studies of Photolysis in Quantum State-Selected Clusters," Asilomar, CA, July 1995.

Nesbitt, D.J., "Probing Intermolecular Potentials and State-to-State Dynamics: Full and Half-Collision Perspectives," PACIFICHEM '95, Honolulu, HI, December 1995.

Nesbitt, D.J., "Watching Molecules Touch: Intermolecular Potentials and State-to-state Dynamics via High Resolution IR Laser Methods," University of Pittsburgh, Pittsburgh, PA, February 1996.

Nesbitt, D.J., "Watching Molecules Touch: Intermolecular Potentials and State-to-state Dynamics via High Resolution IR Laser Methods," Yale University, New Haven, CT, February 1996.

Nesbitt, D.J., "Hydrogen Bonding, Atmospheric Radicals and Nanocrystals: A High Resolution IR Perspective," Harvard University, Cambridge, MA, March 1996.

Nesbitt, D.J., "State-to-State Dynamics with High Resolution IR Lasers: Watching Molecules Touch," University of Chicago, Chicago, IL, March 1996.

Nesbitt, D.J., "Hydrogen Bonding, Radicals and Nanoclusters," Texas Tech University, Lubbock, TX, April 1996.

Nesbitt, D.J., "Molecular Spectroscopy and Dynamics of Transient Species: A High Resolution IR Approach," Institute for Molecular Sciences, Okazaki, Japan, May 1996.

Nesbitt, D.J., "Probing Intermolecular Potentials and State-to-State Dynamics: Full and Half-Collision Perspectives," 12th Symposium on Chemical Kinetrics and Dynamics, Hameji Institute of Technology, Kanaji, Kamigori, Hyogo, Japan, May 1996.

Nesbitt, D.J., "Photochemistry and Photophysics in Quantum State-Selected Species," 12th Symposium on Chemical Kinetrics and Dynamics, Hameji Institute of Technology, Kanaji, Kamigori, Hyogo, Japan, May 1996.

Nesbitt, D.J., "State-to-State Collisional Dynamics of Atmospheric Species," AFOSR Contractors Meeting, University of Colorado, Boulder, CO, June 1996.

Saeta, P., "Squeezing Light From Silicon," Harvey Mudd College, Claremont, CA, January 1995. ▫

APPENDIX C

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

C

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

LABORATORY OFFICE

Katharine B. Gebbie

U.S. Representative and Vice-President, International Committee of Weights and Measures (CIPM).

Member, Executive Committee, Division of Atomic, Molecular, and Optical Physics, American Physical Society.

Vice-Chair, Committee on the Status of Women in Physics, American Physical Society (1995).

Chair, Committee on the Status of Women in Physics, American Physical Society (1996).

Member, Fusion Energy Advisory Committee; Member, Panel on Inertial Fusion Energy, Department of Energy.

NIST Representative, Committee on Optical Science and Engineering, National Research Council.

Point of Contact, Committee on Fundamental Science, National Science and Technology Council.

NIST Representative, Subcommittee on Research, Committee on Fundamental Science, National Science and Technology Council.

Member, Committee to Study Diversity in the Science and Engineering Work Force of the ONR, Office of Naval Research.

American Institute of Physics Subcommittee to select the 1995-1996 winner of the Prize for Industrial Applications of Physics.

Department of Energy Panel to select the 1997 recipient of the Fermi Award.

William R. Ott

NIST Liaison, SDI/BMDO Metrology Projects at NIST.

Co-Chairman, NIST Committee on Society-sponsored Centennial Commemorative Events.

Member, Review Panel on Optics Technology Applications for the BMDO Technology Applications Office.

NIST Liaison, Society of Photo-Optical Instrument Engineers (SPIE).

Member, Program Committee for SPIE Conference, Ultraviolet Atmospheric and Space Remote Sensing, August 1996.

Member, Awards Committee, OSTP Presidential Early Career Awards.

Member, Program Review Committee, Physics Department, St. Joseph's University.

Member, Small Business Innovative Research Selection Committee, helping to select FY96 and FY97 SBIR awards.

Edward B. Saloman

Member, Library Advisory Committee, Optical Society of America.

Barry N. Taylor

Member, Consultative Committee on Units of the International Committee for Weights and Measures.

Chairman, CODATA (Committee on Data for Science and Technology) Task Group on Fundamental Constants, and ex officio member of the U.S. National Committee for CODATA.

Technical Advisor to the U.S. National Committee of the International Electrotechnical Commission on Technical Committee (TC) 25 Matters (TC 25: Quantities and Units and Their Letter Symbols); member of TC 25 Working Group (WG) 1, Advisory and Preparatory.

Member, U.S. Technical Advisory Group (TAG) for International Organization for Standardization (ISO)/TC 12, Quantities, Units, Symbols, Conversion Factors; member International Advisory Panel to TC 12.

Barry N. Taylor (continued)

NIST Representative, Comptroller, and member of the Executive Committee of the Conference on Precision Electromagnetic Measurements.

Member, ISO TAG 4/WG 3, Expression of Uncertainties, and ISO TAG 4/WG 1, International Vocabulary for Metrology (TAG 4: Metrology); member, U.S. TAG for TAG 4.

Member, joint ISO TAG 4, ISO/TC 12, IEC/TC 25, and IEC/TC 1 *Ad Hoc* Working Group on the Definitions of Quantities and Units.

Vice-Chairman, Institute of Electrical and Electronics Engineers (IEEE) Standards Coordinating Committee 14, Quantities, Units and Letter Symbols; member, Subcommittee on Metric Practice.

Member Delegate, National Conference of Standards Laboratories; member, *Ad Hoc* Committee on Measurement Uncertainty; member, American GUM Subcommittee of NCSL Committee Z540, General Requirements for Calibration Laboratories and Measuring and Test Equipment (GUM: Guide to the Expression of Uncertainty in Measurement).

Member, Subcommittee on Standards and Metric Practice of the Metrication Operating Committee of the Interagency Committee on Metric Policy.

Member, U.S. Metric Association Advisory Council.

Member, American Society for Testing and Materials Committee E-43 on SI Practice; member, joint ASTM and IEEE Editorial Task Group on Metric Practice.

U.S. representative to the International Union of Pure and Applied Physics (IUPAP) Commission C2 on SUNAMCO (Symbols, Units, Nomenclature, Atomic Masses and Fundamental Constants); IUPAP Liaison to the IEC; member, U.S. Liaison Committee to IUPAP.

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Robert J. Celotta

Member, Conference on Magnetics and Magnetic Materials, Executive Committee, 1992-1995.

Member, Conference on Magnetics and Magnetic Materials, Program Committee, 1996-present.

Charles W. Clark

Chair, 1995 Tellers Committee, Optical Society of America.

Member, NIST Secretarial Task Force, reporting to Operations Board.

Member, NIST Scientific Computing Planning Team.

Member of Council, NIST HPCC/NII initiative on Systems Integration for Manufacturing Applications.

Member, Selection Committee, 1996 E.O. Lawrence Award of the Department of Energy.

Member, 1996 Tellers Committee, Optical Society of America.

Member, Local Committee, Third International Conference on Quantum Functional Devices.

Member, 1995 Local Committee, Conference on New Methods in Electronic Structure Calculation (ES95).

Member, 1995 Subcommittee on Laser Spectroscopy, Quantum Electronics and Laser Science Conference (QELS '95).

Zachary H. Levine

Councilor of American Physical Society.

Thomas B. Lucatorto

Member, Review Panel for the DoE Atomic Physics Program at Argonne National Laboratory, November 1995

Member, Technical Advisory Panel for the Advanced Technology Program at NIST, 1995.

Member, Executive Council, Division of Atomic Molecular and Optical Physics, APS.

Member, Resonance Ionization Spectroscopy and Its Applications (RIS96) International Advisory Committee.

Robert P. Madden

Member, Council of U.S. Synchrotron Radiation Laboratory Directors.

Member, International Committee of the International Conference on X-Ray and VUV Synchrotron Radiation Instrumentation.

Daniel T. Pierce

Member, International Committee for the International Colloquium on Magnetic Films and Surfaces.

Joseph A. Stroscio

1996 Program chairperson of the Nanometer-Scale Science Division of the American Vacuum Society.

John Unguris

Member, American Vacuum Society Magnetic Surfaces Division Committee.

ATOMIC PHYSICS DIVISION (842)

Jeffrey R. Fuhr

Member of the Working Group 2: Atomic Transition Probabilities, which is a subset of Commission 14 (Atomic and Molecular Data) of the International Astronomical Union.

Richard D. Deslattes

Member, *Ad Hoc* Working Group on the Avogadro Constant, Consultative Committee for Mass, International Committee on Weights and Measures, 1994-present.

Member, The Synchrotron Radiation Instrumentation-Cooperative Access Team at Advanced Photon Source, Argonne, 1994-present.

Alternate Program Manager, Precision Measurement Grants Program, 1994-present.

Member, IUCr Commission on Crystallographic Apparatuses, 1994-present.

Member, International Advisory Board, Journal Physics B, 1992-present.

Member, External Advisory Committee, North Carolina Storage Rings for Technology and Applied Research Project, 1993-present.

Paul Julienne

Member, National Research Council Committee on Atomic, Molecular, and Optical Science (CAMOS).

Member, Thesis Award Committee, Division of Atomic, Molecular, and Optical Physics of the American Physical Society.

Member, Program Committee for Lasers in Physics Symposia, 12th Interdisciplinary Laser Science Conference, October 20-24, 1996.

Yong-Ki Kim

Member, Program Committee for the 10th APS Topical Conference on Atomic Processes in Plasmas, San Francisco, CA, January 14-18, 1996.

William C. Martin

Chair, Working Group on Atomic Spectra, International Astronomical Union.

Member, IAEA Network of Atomic Data Centers for Fusion.

Member, Sponsors Group for Lighting Research of the Electric Power Research Institute (EPRI).

Peter Mohr

Chairman, Advisory Board of the Harvard-Smithsonian Institute for Theoretical Atomic and Molecular Physics.

Member of CODATA (Committee on Data for Science and Technology of the International Council of Scientific Unions) Task Group on Fundamental Constants.

William D. Phillips

DAMOP Program Committee, 1993-95.

DAMOP Publications Committee, 1994-1997.

Vice-Chair of the Division of Laser Science of APS, 1996-1997.

Joseph Reader

Member, DOE Science User's Committee for High-Energy Laser Facilities.

Member, Program committee of the Sixth International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, 1998.

Steven Rolston

Chairman, DAMOP Publications Committee, 1996-present.

Member, NIST Colloquium Committee, 1995-1996.

NIST Research Advisory Committee, 1996-present.

Jack Sugar

Member, Program Committee of the 5th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas.

Cha-Mei Tang

Member, IEEE Board of Directors.

Wolfgang L. Wiese

Member of Organizing Committee, International Astronomical Union, Commission on Atomic and Molecular Data.

Chair, 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).

Chair, Program Committee of the 6th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, 1998.

Chair, First International Conference on Atomic and Molecular Data, 1997.

OPTICAL TECHNOLOGY DIVISION (844)

Clara Asmail

Member, ASTM E-12 Committee, Appearance of Materials, Subcommittee E-12.09 on Optical Properties, F1.06 on Silicon Materials, Process Control.

Member, Sematech, Sematech Particle Counting/Microroughness Roadmap Task Force.

Member, ISO TC172 Committee on Optics and Optical Instruments, Subcommittee 1 on Fundamental Optics.

Member, ASTM F01.06/D-E Particle and Light Scattering Event Task Force.

Yvonne Barnes

Recording Secretary and 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 on Geometric Properties.

Member, Council for Optical Radiation Measurements.

Member, Inter Society Color Council.

Sally Bruce

Member, Electromechanical Systems Engineering Technology Advisory Committee, Montgomery College.

Michael P. Casassa

Member, Ad Hoc Selection Committee, AAAS Technology Policy Science and Engineering Fellowship Program. This committee interviewed finalists and selected Fellows to serve at OSTP and at RAND CTI.

Christopher L. Cromer

Member, CORM subcommittee on Array Radiometry and Photometry.

Raju Datla

Member, Space-Based Observation Systems, Committee on Standards, American Institute of Aeronautics and Astronautics, Sensing Systems Working Group, Subcommittee on IR Systems.

Member, SPIE's International Technical Working Group on Optical Materials.

Member, ASTM E-13.03, Subcommittee on Infrared Molecular Spectroscopy.

Member, CIE, USNC.

NIST/Gaithersburg Liaison to the Calibration Coordination Group (DoD/CCG).

Joseph Dehmer

Member, APS Fellowship Committee.

Member, APS Executive Board.

Member, APS Committee on Applications in Physics.

Member, APS Committee on Committees.

Division Councilor, APS Division of Atomic, Molecular, and Optical Physics.

Member, Executive Committee, APS Division of Atomic, Moleuclar, and Optical Physics.

Chair, Nominating Committee, APS Division of Atomic, Molecular, and Optical Physics.

Joseph Dehmer (continued)

Member, National Science Foundation Committee of Visitors, Review of AMO Physics Program, Physics Division.

Daniel Dummer

Member, IT-2-28 NAPM on Densitometry.

George P. Eppeldauer

Member, CORM Radiometry Subcommittees CR-1 on Sources for Radiometry and Photometry, CR-2 on Array Radiometry, and CR-3 on Photometry.

Gerald T. Fraser

Member, National Aeronautics and Space Administration ESSP AO Science Panel.

Thomas Gentile

Member, American Physical Society.

Charles E. Gibson

Member, ASTM E-20 Committee, Temperature Measurements, Subcommittee E-20.2 on Radiation Thermometry.

Lori Goldner

Member, American Physical Society Committee on Education.

Jonathan E. Hardis

Secretary, U.S. National Committee of the CIE.

Member, CORM Radiometry Subcommittee CR-2.

Member, SEMI FPD Standards Working Group.

Chairman, ASTM Subcommittee E12.06 on the Appearance of (Video) Displays.

Member, ASTM Committee E12 on Color and Appearance.

Participant, OIDA Roadmapping Activities.

Participant, NEMI Roadmapping Activities.

Leonard M. Hanssen

Member, CORM Optical Properties Subcommittee OP-1 on Geometry.

Member, CIE TC2-39 Technical Committee on Geometric Tolerance for Colorimetry.

Edwin J. Heilweil

Member, Membership Committee, NIST Sigma XI Chapter.

Vice Chair, elected July 1996, for 1998 Vibrational Gordon Conference.

Member, Interdisciplinary Laser Science Conference, ILS 1997 Program Committee, Optical Society of America.

Jon T. Hougen

Member, Editorial Board of the Journal of Molecular Spectroscopy.

Member, Scientific Advisory Panel for the C.N.R.S. Laboratory of Molecular Photophysics in Orsay, France.

Member, Advisory Committee for the Institute of Atomic and Molecular Sciences in Taipei, Taiwan.

Jack J. Hsia

President, CIE.

Chairman, CIE TC 2-11 Technical Committee on Goniophotometry.

Ex-Offico, Executive Committee in the 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; and 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.

Member, CORM Optical Properties Subcommittee OP-1 on Geometry.

Liaison, NIST-DOD.

NIST (Gaithersburg) Representative, Optics and Electro-Optics Standards Council.

Physics Laboratory Representative, NIST Measurement Service Quality Committee.

Marilyn E. Jacox

Chairman, Award Recognition Committee, NIST Chapter of Sigma Xi.

Member, International Advisory Committee and Steering Committee of the Ohio State University International Symposium on Molecular Spectroscopy.

B. Carol Johnson

Member, ASTM Subcommittee E20.2 Radiation Thermometry.

Member, Council for Optical Radiation Measurements.

Member, The American Society for Testing and Materials.

Member by invitation to the CCT/CCPR Joint Working Group on Thermodynamics.

Member by invitation in the EOS Calibration Panel (with NASA).

Thomas C. Larason

NIST Consultant, National Conference of Standards Laboratories; National Measurement Requirements Committee, Subcommittee on Electro-Optical Metrology.

Frank J. Lovas

Member, International Advisory Committee for The Ohio State University Internatinal Symposium on Molecular Spectroscopy.

Yoshihiro Ohno

Secretary, CIE Division 2 Physical Measurement of Light and Radiation.

Chairman, CORM Subcommittee CR-3 on Photometry.

Chairman, CIE R2-17 Aviation Photometry.

Chairman, CIE TC2-37 Detector-based Photometry.

Member, Testing Procedure Committee of IESNA.

Member, CIE TC2-11 Gonioreflectometry of Standards Materials.

Member, CIE TC2-16 Characterization of the performance of tristimulus colorimeters.

Member, CIE TC2-24 Users Guide for the Selection of Illuminance and Luminance Meters.

Member, CIE TC2-29 Detector Linearity.

Member, CIE TC2-34 LED Measurements.

Member, CIE TC2-35 CIE Standard for V(λ) and V'(λ).

Member, CIE TC2-40 Characterizing the Performance of Illuminance and Luminance meters.

Member, CIE TC2-41 Industrial Photometry in Developing Countries.

Member, CIE TC2-43 Determination of Measurement Uncertainties in Photometry.

Member, CORM Subcommittee CR-1 on Standard Sources.

Member, CORM Subcommittee CR-2 on Array Spectroradiometry.

Member, CORM Subcommittee CR-4 on Integrating Devices.

Member, CCPR Working group on V(lambda) Corrected Detectors.

Member, SAE ARP5029 Measurement of Anticollision Light.

Delegate to Lamp Testing Engineers Conference (LTEC).

Albert Parr

Member, CORM Radiometry Subcommittee CR-1 on Radiometric Lamp Availability.

CIE Division 2 Reporter, "Application of Cryogenic Radiometry."

NIST representative to CCPR and Member of Subcommittees on UV Standards and Radiometric Lamp Availability, and CCPR Air UV Working Group.

Ex Officio Member, CORM Board of Directors, NIST Liaison.

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.

Member, ASTM Subcommittee E20.2 Radiation Thermometry.

Member, CCPR Air UV Working Group.

Member, CORM Radiometry Subcommittee CR-1 on Radiometric Lamp Availability.

E. Ambler Thompson

Secretary, CIE Division 6 on Photobiology and Photochemistry.

Member, IES Photobiology Committee.

Member, ASTM E13.06 on Molecular Luminescence.

Member, ASTM G-3 on Durability of Nonmetallic Materials.

Benjamin Tsai

Member, ASTM E07 committee on Nondestructive Testing.

Member, ASTM E21 committee on Space Simulation and Applications of Space Technology.

Alfons Weber

Member, Membership Committee, American Physical Society.

Member, International Advisory Committee, International Conference on Spectroscopy, Bombay.

Member, ASTM committee E13.08 on Raman Spectroscopy.

IONIZING RADIATION DIVISION (846)

James M. Adams

Secretary, American Society for Testing and Materials (ASTM) Subcommittee E10.05, Nuclear Radiation Metrology.

Chairman, ASTM Task Group E10.05.05, Activation Reactions.

Member, ASTM Symposium Committee.

Member, American Nuclear Society (ANS) Committee ANS-19.10, Fast Neutron Fluence to Pressurized-Water Reactor Cavities.

Sandra E. Bogarde

Member, NIST Standards Employees Benefit Association Board of Trustees.

Allan D. Carlson

Member, Cross Section Evaluation Working Group (CSEWG), National Nuclear Data Center.

Member, Evaluation Committee of CSEWG.

Chairman, Nuclear Energy Agency Nuclear Data Committee (NEANSC) Subgroup on the $^{10}B(n,\alpha)$ Cross Section Standard.

Member, Standards Subcommittee of the International Nuclear Data Committee.

Member, Subgroup on Experimental Activities of the Working Party on International Evaluation Cooperation of the Nuclear Energy Agency Nuclear Science Committee.

Member, Measurements Committee of CSEWG.

Member, International Program Committee for the International Conference on Nuclear Data for Science and Technology.

Randall S. Caswell

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 Heavy Ions.

Randall S. Caswell (Continued)

Sponsor, ICRU Report Committee on Absorbed Dose Standards for Photon Irradiation and Their Dissemination.

Sponsor, ICRU Report Committee on Medical Applications of Beta Rays.

Sponsor, ICRU Report Committee on Nuclear Data for Radiation Therapy.

Ronald Collé

Member, Interagency Committee on Indoor Air Quality (CIAQ), Radon Workshop.

Louis Costrell

Chairman, Department of Energy (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.

Member, IEEE Nuclear and Plasma Sciences Annual Meetings Committee.

Member, Organizing Committee, 1997 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.

Member, IEC Committee TC45 Working Group 1, Nomenclature.

Member, IEC Committee TC45 Working Group 3, Interchangeability.

Bert M. Coursey

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 des Rayonnements Ionisants (CCEMRI).

Member ANSI Subcommittee N42.2 "ANSI Standards for Nuclear Radiation Detectors."

NIST Representative to the Council on Ionizing Radiation Measurements and Standards (CIRMS).

Marc F. Desrosiers

Member, CIRMS, Radiation Effects Subcommittee.

Co-Chairman, ASTM Committee E10 on Dosimetry, Alanine Standard Subgroup.

David M. Gilliam

Member, ASTM Subcommittee E0.05, Nuclear Radiation Metrology.

NIST Representative to CCEMRI, Section III-Mesures Neutroniques.

Chair, ASTM Task Group E10.05.10, Neutron Metrology.

Member, Symposium Committee, ASTM-EURATOM Symposium Committee on Reactor Dosimetry.

Jimmy C. Humphreys

Member, ASTM Committee E10, Subcommittee E10.01, Dosimetry for Radiation Processing.

Member, ASTM Committee E10, Subcommittee E10.07, Ionizing Radiation Dosimetry and Radiation Effects on Materials and Devices.

Chairman, ASTM Subcommittee E0.01C, Characterization and Performance of a High-Dose Radiation Dosimetry Calibration Laboratory.

Co-chairman, ASTM Subcommittee E10.01D, Use of a Dichromate Dosimetry System.

Jimmy C. Humphreys (Continued)

Co-chairman, ASTM Subcommittee E10.01G, Estimating Uncertainties in Dosimetry for Radiation Processing.

Co-chairman, ASTM Subcommittee E10.01H, Use of Calorimetric Dosimetry Systems for Electron Beam Dose Measurements and Dosimeter Calibrations.

Co-chairman, ASTM Subcommittee E10.01R, Selection and Calibration of Dosimetry Systems for Radiation Processing.

Co-chairman, ASTM Subcommittee E10.01V, Use of a Ceric-Cerous Sulfate Dosimetry System.

J. M. Robin Hutchinson

Secretary, ANSI N42.2: Radioactivity Measurements.

Vice-President, 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 ASTM, Nuclear Fuel Cycle Committee, Environmental Test Methods, C26.05.01.

Member ASTM, Water, Radioactivity Test Methods, D19.

Member ANSI N42.23, Measurement Quality Assurance for Radioassay Laboratories.

Member, CIRMS, Secretary-Treasurer; Organization Committee; Sub-committee on Environmental/Public Radiation Protection.

Vice-Chair, Advisory Committee for the U.S. Transuranium and Uranium Registries.

Member, Multi-Agency Radiological Laboratory Procedures (MARLAP).

Member, National Environmental Laboratory Accreditation Conference (NELAC), Program Committee.

Lisa R. Karam

Member, NIST Mentoring Program Steering Committee.

Member, CIRMS Medical Subcommittee.

Member, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), Alternate Science Representative (committee dissolved, summer, 1995).

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.

Member, National Association of Photographic Manufacturers (NAPM) Technical Subcommittee IT2-31 (X-Ray Image Evaluation).

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. Technical Advisory Group for International Standards Organization (ISO) Technical Committee 198, Working Group 2, Radiation Sterilization.

William L. McLaughlin (Continued)

Member, U.S. Technical Advisory Group for ISO Technical Committee 198, Working Group 2, Packaging.

Chairman, ASTM Committee E10.01, Task Group N "Standard Practice for Dosimetry for a Self-Contained Dry Source Irradiation."

C. Michelle O'Brien

Member, AAPM Task Group on Guidelines for Accreditation of Dosimetry Calibration Laboratories.

Francis J. Schima

Member, IAEA Coordinated Research Program on Gamma-Ray Standards for Detector Calibration.

Member, ANSI Subcommittee N42.2 Radioactivity Measurements.

Stephen M. Seltzer

Member, ICRU Committee on Fundamental Quantities and Units.

Member, ICRU Report Committee on the Dosimetry of External Beta Radiation for Radiation Protection.

Member, NCRP Scientific Committee 86 on "Hot Particles" in the Eye, Ear or Lung.

Member, CIRRPC Sub-Panel on Fluence-Based System of Radiation Risk Assessment.

Member, CIRMS Subcommittee on Medical Applications.

Member, ICRU Advisory Committee on the Conceptual Basis for Dose Quantities in Nuclear Medicine.

Chairman, Joint NCRP/ICRU *Ad Hoc* Committee on Computer Applications.

Consultant, AAPM Radiation Therapy Committee Task Group on Kilovoltage X-Ray Beam Dosimetry.

Member, IAEA Secondary Standards Dosimetry Laboratory Scientific Committee.

Jileen Shobe

Member, ANSI Committee N13.29 "Environmental Dosimetry Performance Criteria for Testing."

Member, ANSI Committee N13.37 "Environmental Thermoluminescent Dosimeters."

Member, HPS Laboratory Accreditation Assessment Committee.

Christopher G. Soares

Member, Health Physics Scientific Subcommittee Work Group ANSI N545, "Performance, testing, and procedural specifications for thermoluminescence dosimetry (environmental applications)."

Member, ANSI Committee N13.29 "Criteria for testing environmental dosimetry performance."

US Technical expert appointed by ANSI to the ISO Technical Committee on Reference Radiations (ISO TC 85/2/2), serving on subgroup 0 (beta-particle reference radiations) and subgroup 5 (photon reference radiations).

Member, AAPM Radiochromic Film Task Group (AAPM/RTC TG55).

Member, Department of Energy Laboratory Accreditation Program (DOELAP) Standard Review Committee.

Member, ICRU Report Committee on Beta Rays for Therapeutic Applications.

Member, AAPM Intravascular Brachytherapy Task Group (AAPM/RTC TG60).

Member, Health Physics Scientific Subcommittee Work Group ANSI N13.11, "Personnel Dosimetry Performance- Criteria for Testing."

Julian H. Sparrow

Chairperson, Joint-Army-Navy-NASA-Air Force (JANNAF) Propulsion Subcommittee "Acceptance Nondestructive Evaluation and Standards."

Alan K. Thompson

Member, ANSI N13-38, Standards for Neutron Personnel Protection Meters.

Michael P. Unterweger

Member, ASTM D022 Committee on Sampling and Analysis of Atmospheres.

Member, IEEE NIM/FASTBUS Committee.

Member, ANSI N42.2, Radioactivity Measurements.

Michael P. Unterweger (Continued)

Member IEEE Nuclear Instruments and Detectors Committee.

EEO Counselor.

Marlon L. Walker

Chairman, Annual Meeting Technical Committee, National Organization of Black Chemists and Chemical Engineers (NOBCChE).

Brian E. Zimmerman

Member, CIRMS Medical Subcommittee.

TIME AND FREQUENCY DIVISION (847)

J. C. Bergquist

Chairman, Fifth Symposium on Frequency Standards and Metrology held October 15-20, 1995 in Woods Hole, Massachusetts.

Member, 1995 Selection Committee for Schawlow Prize in Laser Physics.

Member, Fellowship Selection Committee for the American Physical Society.

Member, NSF Review Committee for LIGO (Laser Interferometer for Gravity-Wave Observatory).

John J. Bollinger

Member, NIST Research Advisory Committee.

Member, Organizing Committee for the Non-neutral Plasma Workshop.

D. Wayne Hanson

Member, Working Group of the Consultative Committee on the Definition of the Second on Two-Way Satellite Time Transfer.

Member, U.S. delegation to the ITU-R Working Party A of Study Group 7, International Telecommunication Union. This working party deals with time and frequency issues.

Wayne Itano

Member, Publishing Technology Committee, Optical Society of America.

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.

Lisa M. Nelson

Co-Chairman, Civilian GPS Service Interface Committee (CGSIC).

Thomas Parker

Chairman, Executive Committee for the annual IEEE International Frequency Control Symposium.

General Chairman, 1997 IEEE International Frequency Control Symposium.

Member, GPS Interagency Advisory Council (GIAC).

Donald B. Sullivan

Member, Consultative Committee on the Definition of the Second.

Member, Commission A on Time and Frequency, International Telecommunications Union - Radiocommunications Sector.

Member, Executive Committee for the Annual IEEE Frequency Control Symposium.

Chairman, Executive Committee for the Conference on Precision Electromagnetic Measurements (CPEM).

Fred Walls

Chairman, Technical Program Committee for the Annual IEEE International Frequency Control Symposium.

Member, Technical Program Committee of the European Frequency and Time Forum.

Marc Weiss

Member, Working Group on International Atomic Time TAI of the Consultative Committee on the Definition of the Second.

Member, Telecommunication Industry Subcommittee on Time and Synchronization.

Marc Weiss (Continued)

Member, Working Group on GPS Time Transfer Standards of the Consultative Committee on the Definition of the Second.

David J. Wineland

Member, NIST Precision Measurement Grants Committee.

Member, National Academy of Science.

Member, Committee on Atomic, Molecular, and Optical Science (National Academy of Sciences).

Member, organizing committee for the Nobel Symposium on Trapped Charged Particles and Fundamental Physics.

QUANTUM PHYSICS DIVISION (848)

P.L. Bender

Member, Control/Structure Integration Program Advisory Committee, NASA.

Member, Lunar Laser Ranging Management and Operations Working Group.

Member, Space Interferometry Science Working Group, NASA.

T.S. Clement

Member, University of Colorado Computational Plasma Physics Search Committee.

Member, University of Colorado Physics Graduate Committee.

E.A. Cornell

Subcommittee member for QELS 1995 Laser Spectroscopy program.

Member of the JILA Search Committee, 1995.

Member, University of Colorado Matter Physics Search Committee, 1995.

G.H. Dunn

Councilor, American Physical Society.

Executive Committee, Division of Atomic Molecular and Optical Physics of the American Physical Society.

Program Committee of the Topical Conference on Atomic Processes in Plasmas.

Chairman and member of International Scientific Committee, 1996-97 International Conference on the Physics of Electronic and Atomic Collisions (ICPEAC).

Executive Committee of the Topical Group on Precision Measurements and Fundamental Constants (Council Liaison).

Nominating Committee of Division of Atomic and Molecular Optical Physics.

Nominating Committee of the Topical Group on Precision Measurements and Fundamental Constants.

Vice-Chair, 1994-95 International Conference on the Physics of Electronic and Atomic Collisions (ICPEAC).

Member, Panel on Public Affairs (POPA) of the American Physical Society. Chaired subcommittee to examine impact on physics of change in national labs. Member, Steering Committee.

Chair, JILA Search Committee.

J.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, IAG Commission III, International Gravity Commission.

Benchmark participant for JILA for the Griffith University (Australia).

A.C. Gallagher

Chairperson at European Conference on Electronic and Atomic Collisions.

Member, NREL Amorphous Silicon Development Team.

Benchmark participant for JILA for the Griffith University (Australia).

J.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, National Academy of Science.

S.R. Leone

Steering Committee, Laser Science Topical Group, American Physical Society, 1995.

Councilor, American Physical Society.

Member, Basic Energy Sciences Advisory Committee, Department of Energy.

Advisory Committee, Institute for Atomic and Molecular Science, Taiwan.

Chair, Review Committee, *Journal of Chemical Physics*.

Department of Chemistry and Biochemistry Faculty Search Committee.

Member of JILA Search Committee.

Award Committee, American Physical Society.

J.L. Linsky

Member, NASA Science Working Group to design and oversee development of the Hubble Space Telescope Imaging Spectrograph and the Far Ultraviolet Spectrograph Explorer satellite.

Member, Science Working Group for the Advanced X-ray Astronomical Facility (AXAF).

D.J. Nesbitt

Co-Chair, 1995 Gordon Conference on "Atomic and Molecular Interactions."

Chairman, Chemical Physics Program, University of Colorado, Boulder.

Chair, 1996 Gordon Conference on "Atomic and Molecular Interactions."

Benchmark participant for JILA for the Griffith University (Australia).

Chair, American Physical Society Fellowship Selection Committee. ▫

APPENDIX D

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

D

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

LABORATORY OFFICE

R.A. Dragoset worked with J.T. Hougen and R.D. Suenram of the Optical Technology Division to sponsor the workshop "Molecular Spectra Data for the 21st Century," NIST, Gaithersburg, MD, December 5-6, 1996.

W.R. Ott organized and chaired a session on Instrumentation for UV Remote Sensing at the SPIE Conference on Ultraviolet Atmospheric and Space Remote Sensing, Denver, CO, August 1996.

W.R. Ott is chairman and organizer of the biweekly NIST Staff Colloquium Series.

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

R.J. Celotta, D.T. Pierce, and M. Stiles served on the Organizing Committee, "Workshop on Fe/Cr/Fe Magnetic State," NIST, Gaithersburg, MD, November 6, 1996.

C.W. Clark served on the Local Committee, "Workshop on New Methods in Electronic Structure Calculation," St. Mary's College of Maryland, St. Mary's City, MD, May 19-22, 1995.

M.D. Stiles served as Chair, Local Committee, "Workshop on New Methods in Electronic Structure Calculation," St. Mary's College of Maryland, St. Mary's City, MD, May 19-22, 1995.

ATOMIC PHYSICS DIVISION (842)

W.C. Martin and J. Reader worked with the Electric Power Research Institute (EPRI) to organize a meeting on Lighting Research, held at NIST, Gaithersburg, MD, January 24, 1996.

OPTICAL TECHNOLOGY DIVISION (844)

G. Eppeldauer coordinated an Internal Workshop on Future Infrared Transfer and Working Standard Radiometer Developments for Spectral Radiant Power and Irradiance Measurements, NIST, Gaithersburg, MD, March 14, and 21, 1996.

R.U. Datla, organized the NIST participation for the Fifth Symposium on Infrared Radiometric Sensor Calibration held at Space Dynamics Laboratory, Logan, UT, May 8-10, 1995.

R.U. Datla organized the Workshop on Standards for IR - FPAs & Imaging Systems for DOD/BMDO Applications, NIST, Gaithersburg, MD, September 26, 1995.

B.C. Johnson (NIST) and Stan Hooker (NASA/GSFC) organized the SIRREX-4 (SeaWiFS Intercalibration Round-Robin Experiment) Workshop, held at NIST, Gaithersburg, MD, May 3-10, 1995.

B.C. Johnson organized the SIRREX-5 Workshop held at NIST, Gaithersburg, MD, July 23-30, 1996.

S.R. Lorentz organized the NIST participation for the Sixth Symposium on Infrared Radiometric Sensor Calibration held at Space Dynamics Laboratory, Logan, UT, May 7-9, 1996.

Y. Ohno served as the organizer and chairperson for the CIE Division 2 Workshop, "Recent Technologies on Optical Radiation Measurements" held in New Delhi, India, November 2, 1995.

Y. Ohno served as the organizer and chairperson for the Photometry Session at CORM 96, Gaithersburg, May 21-23, 1996.

Y. Ohno serves as the Secretary of CIE Division 2, and is responsible for organizing the annual Division meeting. The 1996 CIE Division 2 meeting was held in Vienna, Austria, on August 31, 1996.

A.E. Thompson organized a Workshop on Low-Level Light Standards for Luminometry: Assessing Needs for Clinical and Analytical Luminescence Measurements, held at NIST, Gaithersburg, MD, May 1, 1996.

A.E. Thompson organized a one day Workshop on Advanced Methods and Models for Appearance of Coating and Coated Objects, held at NIST, Gaithersburg, MD, May 20, 1996.

IONIZING RADIATION DIVISION (846)

B.M. Coursey and S.M. Seltzer organized and sponsored a meeting of Task Group 51 of the American Association of Physicists in Medicine at NIST, Gaithersburg, MD, on April 1-2, 1996.

B.M. Coursey organized a workshop cosponsored by NIST and the Medical Applications Subcommittee of the Council on Ionizing Radiation Measurements and Standards at NIST, Gaithersburg, MD, April 3, 1996.

J.M.R. Hutchinson and K.G.W. Inn helped organize and sponsor one session of the Council on Ionizing Radiation Measurements and Standards' annual meeting, November 28-30, 1995.

K.G.W. Inn and J.M.R. Hutchinson helped organize a CIRMS Science and Technology subcommittee on Environmental Radiation Protection at a special session at the Health Physics Society Meeting in Boston, MA, June 25, 1995.

K.G.W. Inn, W. Burnett, M. Schultz, Z.-C. Lin and J.W.L. Thomas organized the international workshop on "Radionuclide Speciation in Soils and Sediments" at NIST, Gaithersburg, MD, June 13-15, 1995.

K.G.W. Inn organized the NIST program session at the Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Boston, MA, November 17, 1995.

L.R. Karam and B.M. Coursey, in cooperation with George Mason University, organized and hosted a Workshop on Ultrahigh Sensitivity Quantitation Methodologies and Instrumentation for Biomedical Applications, at NIST, Gaithersburg, MD, July 14, 1995.

B.E. Zimmerman and B.M. Coursey sponsored a workshop to discuss the current status of research in bone palliation radiopharmaceuticals and to identify future measurement needs in nuclear medicine, at NIST, Gaithersburg, MD, September 27, 1996.

TIME AND FREQUENCY DIVISION (847)

M. Weiss and W. Ortega organized a Workshop on Synchronization in Telecommunications Systems, Boulder, CO, February 22-24, 1995.

Dave Howe chaired the annual Time and Frequency Seminar: Introduction – Level I, June 26-27, 1995, Boulder, CO.

Dave Howe chaired the annual Time and Frequency Seminar: Fundamentals - Level II, June 28-30, 1995, Boulder, CO.

J. Bergquist served as symposium chairman and W. Ortega served as conference coordinator for the Fifth Symposium on Frequency Standards and Metrology, jointly sponsored with the Air Force Office of Scientific Research, Woods Hole, MA, October 15-19, 1995.

M. Weiss and W. Ortega organized a Workshop on Synchronization in Telecommunications Systems, Boulder, CO, February 21-23, 1996.

D. Howe chaired the annual Time and Frequency Seminar: Introduction – Level I, Boulder, CO, June 24-25, 1996.

D. Howe chaired the annual Time and Frequency Seminar: Fundamentals – Level II, Boulder, CO, June 26-28, 1996.

The Time and Frequency Division participated with other NIST units in presenting training seminars at the Measurement Science Conference, Anaheim, CA, January 22-23, 1996. The Division seminar was on Properties of Oscillator Signals and Measurement Methods.

QUANTUM PHYSICS DIVISION (848)

G.H. Dunn was the Chairman of ICPEAC in 1996.

The 20th annual CU Wizards program, an informal introduction to physics, astronomy and chemistry is a monthly program for students in grades 5 through 9. The 1995-96 program includes J. Faller and D. Nesbitt. ▫

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*.

Taylor, B.N., Editorial Board, *Metrologia*.

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Celotta, R.J., Co-editor, *Experimental Methods in the Physical Sciences*, Academic Press Series.

Clark, C.W., Member, Editorial Board, *Journal of Physics B: Atomic, Molecular, and Optical Physics*.

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ATOMIC PHYSICS DIVISION (842)

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OPTICAL TECHNOLOGY DIVISION (844)

Joseph Dehmer, Co-editor of Proceedings, Conference on Synchrotron Radiation – 1995, Advanced Photon Source.

Joseph Dehmer, Associate Editor, Advances in Ion Chemistry and Physics.

Hougen, Jon, Member, Editorial Advisory Board, Journal of Molecular Spectroscopy.

IONIZING RADIATION DIVISION (846)

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TIME AND FREQUENCY DIVISION (847)

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APPENDIX F

INDUSTRIAL INTERACTIONS

F

INDUSTRIAL INTERACTIONS

COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENTS – CRADAs

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

■ **Infrared Microscope Optical Design.** The Photon Physics Group works with the Spectra-Tech Company, Shelton, CT under the terms of a CRADA, investigating new concepts in infrared microscope optical design for optimal matching of commercial instrumentation to the characteristics of a synchrotron infrared source. Spectra-Tech has long been a leading supplier of infrared microscopes for industrial and research applications. Their microscopes come equipped with a conventional infrared source, known as a globar, for sample illumination, and the present optical design of the microscope is optimized for that source. Recently it was demonstrated that a synchrotron light source, because it is several orders of magnitude brighter than any conventional source, could produce vastly superior performance. SURF II is just such a synchrotron light source, and we are presently establishing an infrared microscope facility at SURF II to avail the industrial and research communities of this performance advantage. Because the geometrical characteristics of the globar and synchrotron sources are so different, up to another order of magnitude could be gained by customizing the optics to work with synchrotron radiation.

■ **Standard Reference Data for use in Ab-Initio Materials Modelling.** The Electron Physics Group and Photon Physics Group work with Bisoym Technologies, Inc., San Diego, CA, under the auspices of a CRADA to develop standard reference data and improved techniques for use in *ab-initio* materials modelling. Biosym is a leading producer of molecular modelling software that numercially solves the many-electron Schrödinger equation to predict the structure and properties of large molecules and solids. A number of approximations must be made to solve these equations in practice, and for the most advanced methods currently in use, the errors associated with the approximations are not well quantified. Standard reference data are being generated for evaluation of these methods; the first compilation can be viewed on the World Wide Web at http://math.nist.gov/DFTdata/

ATOMIC PHYSICS DIVISION (842)

■ **X-Ray Beam Manipulation.** The Quantum Metrology Group works with X-Ray Optical Systems, Inc.(XOS), Albany, NY, under the terms of a CRADA established in 1992. Joint research is performed on the physical principles connected with redirecting, focusing, and collimating x-ray beams by means of multiple channels. The optics are based on the well-known property that x-rays undergo specular reflection when incident on flat solid surfaces at angles smaller than the critical angle for total external reflection. The optics have the potential to relax previously existing constraints by providing options to: increase beam intensity, improve beam collimation, increase beam uniformity, provide flexibility in beam orientation and source to target distance, affect energy selection, and reduce background radiation.

XOS is investigating using the optics for numerous applications including material analysis, x-ray lithography, medical therapy, and medical imaging.

In response to ARPA and the ATP program, and in the context of a CRADA with X-ray Optical Systems (XOS) in Albany, NY, we designed, constructed, and delivered a high-flux micro-focused x-ray source and detector to XOS for the testing of capillary optics at 1 keV. The heart of the apparatus is a custom electron gun which can provide 1 mA of current into a 0.25 mm spot at low energies onto an actively cooled anode. XOS reports performance which exceeds requirements. Individual optic fibers are to be assembled into an x-ray collimator for a demonstration project of proximity printing.

■ **X-ray Application of Charge Injected Devices.** The Quantum Metrology Group works with CID Technologies, Inc. (CIDTEC), Liverpool, NY, under the terms of a CRADA established in 1993. This joint research investigates the suitability of Charge Injection Devices (CIDs) for registration of x-ray images. The x-ray energy range of primary initial interest is from 3 keV to 30 keV. There are two classes of applications which are of significance to existing programs in the Quantum Metrology Group. In both cases the x-ray images are produced by crystal diffraction spectrometers. One of the applications is the recording of very weak images requiring that the CID be operated at temperatures considerably below ambient to permit the needed long integration times. The second application is to a situation where much higher x-ray flux is available and the need is to accumulate spectral information in exposure times of the order of one second.

■ **Crystal Diffraction Spectrometry for kV Standardization in Mammography.** The Quantum Metrology Group works with Radcal Corporation, Monrovia, CA under the terms of a CRADA established in 1994. This joint research effort is from development and broad dissemination of clinically useful embodiments of the NIST technique for non-invasive determination of the high voltage applied to radiological x-ray sources, particularly those used in mammography. In general, the NIST effort will emphasize validation and extension of the basic technology and make available to Radcal certain prototype devices with which to gain experience in the application of x-ray spectroscopy to the characterization of mammographic sources. The Radcal component will emphasize issues of manufacturability of commercially viable and clinically useful systems and their adaptability to the full range of radiological systems which constitute the current installed base.

■ **Calibration of Rapid Method for Semiconductor Crystal Axis Orientation from Surface Morphology.** The Quantum Metrology Group works with EXOTECH, INC., Gaithersburg, MD under the terms of a CRADA established in 1994. This joint research effort is to determine the accuracy which can be achieved in measurement of the crystal lattice plane orientation of semiconductor materials from their surface morphology. If favorable results are achieved, this method can provide a very rapid means for making this measurement during the production process and could be used in quality control tests to improve yields.

■ **CRADA with IBM.** Y.-K. Kim has a CRADA with IBM on the development of multiconfiguration relativistic wave function code for atoms. Parts of the existing codes have been converted and verified on NIST's SP2 parallel computer. A recent discovery that multiconfiguration relativistic wave functions may have incorrect nonrelativistic limits indicates that the use of non-orthogonal radial functions may lead to more compact wave functions than the traditional orthogonal radial functions. This possibility will be explored further when resources for a postdoc becomes available.

■ **CRADA with the Advanced Lithograph Group.** The EBIT project renewed a CRADA with the Advanced Lithography Group (ALG), a consortium of industrial, government, and university groups who are working to develop and commercialize a projection ion lithography system to outperform conventional photolithography systems at and below 180 nm linewidth.

■ **Atomic Data for Lighting Research.** The Atomic Spectroscopy Group is working with lighting-industry scientists and the Electric Power Research Institute (EPRI) to develop and implement a research program at NIST to produce basic atomic data needed for lighting research. A NIST/EPRI CRADA for partial support of such work at NIST is now being negotiated.

■ **Mercury-Free Fluorescent Lighting.** We have, jointly with the Optical Technology Division, a CRADA with General Electric Corporate Research and Development, Schenectady, NY, to assist GE in their ATP program entitled "Mercury-free fluorescent lighting system." The goal is to develop a mercury-free replacement for existing fluorescent lamps. NIST is addressing the following issues identified by GE researchers to advance their goal:

- Experimental determination of important cross sections for excitation from all significantly populated lower states (i.e., metastable states) to all important upper states.
- Vacuum ultraviolet source and detector radiometry to accurately calibrate the ultraviolet emission from the plasma and compare it to model calculations.

OPTICAL TECHNOLOGY DIVISION (844)

■ **Filter Radiometers High-Flux UV Microwave Source.** The Optical Sensor group works with Fusion Semiconductor Systems, Rockville, MD under the auspices of a CRADA. Joint research is performed to study the stability and calibration accuracy of the UV meters used in irradiance measurements of high-intensity UV microwave discharge sources used in semiconductor resist photostabilization.

■ **High Accuracy Instrumentation for Photometry and Colorimeter.** Optical Sensor Group works with Graseby Optronics, under the auspices of a CRADA. Joint research has been performed on High Accuracy Instrumentation for Photometry and Colorimetry. A theory for improved method of tristimulus colorimeters has been developed by NIST, and it has been experimentally verified using instruments developed by Graseby Optronics. A technical presentation was made at SID96 Conference in May 1996. This CRADA was completed in FY96.

■ **Total Spectral Flux Realization.** Optical Sensor Group works with Labsphere, Inc., under the auspices of a CRADA. Joint research is being performed on Total Spectral Flux Realization Using an Integrating Sphere & External Light Source. A new method of realizing total flux scale has been developed by NIST and implemented for the NIST luminous flux scale. Joint research is being performed to apply this new method for the realization of spectral total flux scale.

■ **Mechanistic Data for Catalytic and Co-polymerization reactions Using Femtosecond Infrared Spectroscopy.** The Laser Applications Group works with DuPont Central Research and Development, Wilmington DE under a CRADA, entitled "Mechanistic Studies of Catalyzed Hydrocyanation using Ultrafast Broadband Infrared Spectroscopy." The Group also works with DuPont Printing and Publishing, Leeds, UK under a separate CRADA, entitled "Mechanistic Studies of Printing Plate Co-Polymerization Reactions using Ultrafast Broadband Infrared Spectroscopy."

■ **AIGER.** Spectroscopic Applications Group works with American Industry Government Emissions Research Consortium (AIGER) under the auspices of a CRADA. The possibilities of using Fourier Transform Microwave Spectroscopy in the automobile industry and in the development of a fast oxygenated-hydrocarbon analyzer are being investigated.

IONIZING RADIATION DIVISION (846)

■ **Multi-Photon Detection for Low-Level Radionuclide Analyses.** The research project that comprises the technical effort of the CRADA with BioTraces, Inc., focuses on evaluating a new device for the measurement of radiolabelled compounds of very low specific activities. Due to the extremely low residual backgrounds achieved by this system, the MultiPhoton Detector (MPD) can be used in situations where conventional detection systems would be inadequate. This will permit the use of much less radioactivity in biomedical and other studies, thereby reducing radioactive wastes and costs associated with its disposal. The Division is supporting the goals of BioTraces by (1) performing high pressure liquid chromatographic (HPLC) analyses in various biomedical applications; (2) providing expertise and experimental collaboration on molecular biological applications of the MPD; (3) demonstrating the potential applicability of MPD in biomedical tracing, imaging and therapy; and (4) providing various electron-capture nuclide standards and other radioisotopes as needed for calibration and applications.

■ **Radiochromic Gel Development.** The research that comprises the technical effort of this CRADA with MGS Research, Inc., focuses on the development of a novel approach to the measurement of radiation dose and dose distributions in three dimensions using MRI and optical scanning. NIST and MGS have recently developed radiochromic gels which change color (detectable by tomographic optical scanning) and polymer gels which change molecular structure (detectable by NMR spectrometers, clinical magnetic-resonance imagers, spectrophotometers, and tomographic optical scanners) with exposure to radiation. Such gels offer the possibility of replacing the ionization chamber with a tissue-equivalent device for the measurement of dose-to-tissue and for the measurement of three-dimensional dose distributions. Polymer gels in vessels which meet the requirements of specific experiments are prepared by MGS Research while radiochromic gels are prepared by NIST. All irradiations are done at NIST.

■ **Monoenergetic Photon Beam Production.** C.E. Dick in the Radiation Interactions and Dosimetry Group works with SFA, Inc., of Landover, MD, under the auspices of a CRADA. Research is proceeding to develop monoenergetic photon beams by the bombardment of crystalline targets with energetic electron beams. Construction of a beam-line at the MIRF has been initiated and the beam has been transported to the end of the beam-line. A goniometer to hold the crystal has been obtained on loan from Lawrence Livermore Laboratories and is currently being refurbished for installation on the beam line. The hardware for manipulating the goniometer and the software for computer control are nearing completion. Vacuum hardware and the primary photon detector are being acquired.

■ **A New Type of Diagnostic X-Ray Tube.** The Radiation Interactions and Dosimetry Group works with Rayex, Corp. of Gaithersburg, MD, under the auspices of a CRADA. Research is proceeding in the design and construction of a new type of diagnostic x-ray tube for use in existing diagnostic radiology equipment. This tube will be optimized for significantly higher x-ray output and increased lifetime than current conventional x-ray tubes. The technology involves a fundamental change in the geometry used in x-ray tube design that was optimized through extensive electron/x-ray Monte Carlo calculations using a world-leading computer code developed at NIST. The tube has been designed and a prototype has been constructed and is under test at the present. Rayex is funded for this project by SBIR from the NIH. Two Rayex employees work full time in the NIST laboratories.

■ **Interpenetrating Polymer Network Formation by Electron-Beam Curing of Acrylate Epoxy Resin Blends.** Under a CRADA with the University of Maryland Department of Materials and Nuclear Engineering, an experimental study has been made to develop continuous manufacturing processes of complicated structures of epoxy resin-graphite fiber composites which require a high degree of control of the level and dispersed of process polymerization. This goal was achieved by using a two-step radiation curing process involving different blends of unmodified epoxy resins with modified acrylate epoxy resins. The first step is designed to achieve partial curing of the blend by using high-energy electron beam (e-beam) irradiation, followed by full thermal curing. Higher glass transition temperature (T_g) values are obtained by using modified fully unsaturated resins with unmodified epoxy resins, as compared to blends of modified monosaturated resins with unmodified epoxy resins. No partial curing can be accomplished by e-beam irradiation of the unmodified epoxy resin alone. The present results demonstrate that the introduction of the fully-unsaturated resin blend increases the efficiency of the e-beam radiation curing through free-radical polymerization and then free-radical cross linking, which leads to IPN formation.

■ **Automation of Alanine Dosimeter Measurements.** M.F. Desrosiers is working under a CRADA with Bruker Instruments, Inc., Billerica, MA, to develop an automated alanine dosimeter sample changer for electron paramagnetic resonance (EPR) spectrometers, and the appropriate software, suitable for routine measurement in the dose range for radiation therapy (1 Gy to 50 Gy) and for industrial radiation processing (>100 Gy).

■ **Alanine Film Dosimeter for Electron-Beam Processing.** In a CRADA with W.R. Grace & Co., Columbia, MD, M.F. Desrosiers is working to develop a dosimetry system for electron beams, based on incorporating alanine detector material into polymer films, and a readout method for the film detector using electron paramagnetic resonance (EPR).

■ **Electron-Beam Waste-Water Treatment.** Electron beam studies, centered at the NIST MIRF facility, have proceeded in several areas. Under a CRADA with the Department of Materials and Nuclear Engineering of the University of Maryland, electron beam induced degradation of toxic metal salts in aqueous solutions has been demonstrated, with efficiencies of precipitation of mercury as high as 99.9% at typical radiation processing absorbed doses (~40 kGy). The model radiation chemical reactions in such systems has been substantiated, and the roles of oxygen and hydroxyl radical scavengers (e.g., ethanol) have been established. In collaboration with the University of Miami, an aqueous dye dosimeter is being developed for quality control in the electron beam dehalogenation (e.g., PCBs) and purification of toxic ground water supplies. NIST is also helping the DoE in evaluating the progress of legislated contracts on hospital waste treatment by electron beams as a viable alternative to incineration. Electron beam treatments for remediation of several environmentally hazardous wastes are being developed as emerging U.S. technologies for small business entrepreneurs.

■ **Spectrometric Microdensitometer System for Radiochromic Dose Mapping.** W.L. McLaughlin and C.G. Soares are working with the Photoelectron Corporation of Waltham, MA, under a CRADA to develop a system for the imaging of exposed radiochromic films for quantitative dosimetry in two dimensions. In the program, various elements of the system, the light source, lens, CCD camera, computer interface, and software, will be evaluated in terms of spectral output, sensitivity, dynamic range, noise, contrast, image distortion, spatial resolution, stability, and ease of use. Performance will be judged against the laser scanning microdensitometer. Success would lead to the availability of a fast, reliable, and perhaps superior system for reading the radiochromic films used in industrial and medical dosimetry.

■ **Space-Shielding Radiation Dose Calculations.** S.M. Seltzer is working with the Severn Communications Corporation of Millersville, MD, on the incorporation of his latest space-shielding radiation transport database and algorithms into Severn's software package called Space Radiation. The prediction of radiation dose within satellites and spacecraft, and its effects on electronic devices, is critical for the design, feasibility, and cost studies of spaceborne systems. Such predictions require knowledge of the environment of radiation incident on the spacecraft, the penetration of the radiation, and the dose delivered to the location within the spacecraft, and the radiation effects on the system. Through a CRADA, the collaboration will replace the older SHIELDOSE code and database used to predict the radiation dose within spacecraft in Severn's Space Radiation with NIST's recently completed SHIELDOSE-2. The NIST work, developed with NASA support, is based on extensive Monte Carlo calculations for electrons, bremsstrahlung, and protons. Combining this with appropriate radiation environment models, orbit integration routines, and a well-developed treatment of cosmic rays, Severn's software will provide a complete package that incorporates components recognized as standards in the industry.

■ **X-Ray Imaging Camera for Radiation-Therapy Dose Mapping.** Under a CRADA, the Rayex Corporation is working with the Radiation Interactions and Dosimetry Group of the Ionizing Radiation Division to develop an x-ray imaging camera with the potential of simultaneously measuring in real time the profiles of tissue density and of radiation dose in a patient undergoing radiation therapy. The efficacy of cancer treatment by beams of ionizing radiation is greatly dependent on the precision with which a large radiation dose can be delivered to the tumor site, while holding to sufficiently low dose levels elsewhere in order to spare nearby healthy structures. Optimizing the dose distribution is the goal of much current work on focussing radiation using either scanned pencil beams or shaped beams from multiple directions. Delivered doses are *predicted* using elaborate treatment planning algorithms based on phantom measurements done in rather simple geometry. Nothing is presently available with which an on-line, real-time, non-invasive measurement of the actual dose delivered can be made (and possibly used to control the dose delivery).

■ **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. Radiopharmaceuticals used for radioassay and a radiotherapy are prepared and submitted as calibrated materials or as blinds to the participating companies.

■ **Standards and Traceability of the Nuclear Power and Standards Suppliers.** The Radioactivity Group works under a CRADA with a group combining 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.

TIME AND FREQUENCY DIVISION (847)

■ **Frequency Tunable External Cavity Laser Diodes.** Leo Hollberg is collaborating with Spectra Diode Laboratories, Inc. on the development of precision, tunable, diode-laser sources for a variety of measurement applications.

■ **Miniature Cesium Atomic Clock.** Bob Drullinger and Fred Walls of NIST are working with Westinghouse Electric Corp. on the development of a miniature cesium atomic clock. NIST's long experience with atomic clock physics and electronics complements the microfabrication technology which Westinghouse brings to the project. In the course of this work, the component of Westinghouse involved in this work was sold to Northrup-Grumman Corp., but the interaction has continued.

■ **Phase Noise Standards.** Fred Walls has recently completed a collaboration with Techtrol Cyclonetics, Inc. on the development of phase noise standards for the microwave region. The company now markets a product based on this collaboration.

QUANTUM PHYSICS DIVISION (848)

■ **Calibration of Optical Spectrum Analyzers and Tunable Diode Lasers.** D. Nesbitt has joined with S. Gilbert and D. Franzen of the Electronics and Electrical Engineering Laboratory of NIST in a CRADA with Hewlett Packard for the development of wavelength calibration equipment for optical spectrum analyzers and tunable diode lasers. The project will generate portable frequency standards based on molecular overtone absorption in gas cells. The 1500 nm region can be probed with broadband emission from a near infrared light source. The light transmitted through the gas cell contains the molecular "notches" due to the rovibrationally resolved HCN spectrum, which can be used as either an in-house or internal frequency standard for the HP 71450A and 71451A Optical Spectrum Analyzers.

■ **Development of Piezoelectric Assemblies and Test Procedures for External-Cavity Tunable Diode Lasers.** E. Cornell has a CRADA with Melles-Griot to develop large-range piezoelectric positioners, and techniques for testing performance of external-cavity tunable diode lasers. Melles-Griot may use such equipment and techniques for in-house development and/or produce new products based on such equipment and technology.

■ **External Laser Stabilizer for Laser Frequency.** J.L. Hall has teamed up with M. Jefferson of IBM's Almaden Research Center in San Jose, CA, in a CRADA to finalize an improved design for an external laser stabilizer that will be licensed for small-scale manufacturing. IBM is currently using the stabilizer on a dye laser to probe spectral hole-burning effects in rare-earth, ion-doped crystals of prospective interest in information storage applications. Hall's labs are using the technique to pursue optical frequency standards using sharp resonances in optically-cooled atoms, in sub-Doppler molecular overtone spectroscopy, and for other ultrahigh resolution spectroscopy applications.

■ **Research in the Development of Improved Iodine-Stabilized Lasers.** J.L. Hall and Winters ElectroOptics have enacted a CRADA directed toward making substantial improvements in the He-Ne laser. The Iodine-stabilized He-Ne laser is one of the primary dissemination/working standards of frequency/wavelength, but until recently there has been no readily available commercial product for high precision research or NIST calibration services. If further developed to be more robust and easier to operate, it could become much more useful as a stable reference laser for both industrial and research applications. It will also be the standard for proving the accuracy of diode laser systems for many years, and will ultimately dominate the global commercial length standards market.

■ **Methods for measuring propagation characteristics of lasers.** L. Austin and T. Johnston of Coherent, Inc., and J.L. Hall are collaborating under a CRADA to develop a useful methodology for measuring and characterizing geometrical aspects of laser beams emitted by practical sources, particularly diode lasers and other solid state sources. This knowledge will be applied to developing low-threshold optical parametric oscillators.

■ **Development of a Small Laser Interferometric Ballistic Absolute Gravimeter.** Micro-G Solutions, the only U.S. firm producing absolute gravimeters commercially, and J. Faller have a CRADA devoted to the development of a new absolute gravimeter. The current state-of-the-art instrument is, while exquisitely precise, a relatively large (desk sized) and expensive (about $300 K) instrument. The new instrument is intended to be much smaller, lighter, and easier for a single person to transport and set up, making it much more attractive as a general research tool and geophysical field instrument. These improvements will push the state of the art in nano-metrology and signal processing.

OTHER INDUSTRIAL INTERACTIONS

ATOMIC PHYSICS DIVISION (842)

■ **ATP Program for Mercury-Free Lighting.** Y.-K. Kim participated in an ATP-based NIST program (monitored by Jim Roberts) to provide atomic collision cross sections for mercury-free lighting. The applicability of a new theory to calculate electron-impact ionization and excitation cross sections is being tested on heavy atoms. The new theory is simple to use and provides an analytic expression as a function of the incident electron energy, which makes it suitable for modeling of plasmas generated in a fluorescent bulb.

OPTICAL TECHNOLOGY DIVISION (844)

■ **Nonlinear Optical Studies of Liquid Crystal Displays.** The Laser Applications Group, in collaboration with the Surface Dynamical Processes Group in CSTL, is developing laser diagnostic techniques for the structure of epoxide alignment layers used to orient liquid crystals in LCD's, jointly with Alliant Tech Systems (an ATP awardee).

■ **Gold-Black Depositions.** J.P. Rice of the Optical Technology Division interacted with Cambridge Research Instrumentation (CRI), Cambridge, MA, by coating novel infrared focal-plane arrays from Texas Instruments with gold-black, a lightweight optical absorber. Under an SBIR, CRI is developing a total solar images using the gold-black coated arrays.

■ **IR Instrumentation.** A.L. Migdall consulted with GE Reuter Stokes on IR measurement instrument, April 1996.

■ **Development of Infrared Neutral Density Filters.** The Optical Materials and Infrared Technology Group works with Luxel, Inc. of Friday Harbor, WA on the development of neutral density filters for the 2 μm to 25 μm wavelength range, with optical densities ranging from 1 to 10. The filters consist of thin metallic coatings on dielectric substrates. Coatings on 0.25 mm Si substrates are being produced to serve as SRM's for infrared regular spectral transmittance. In addition, metallic coatings on ultrathin (100 nm) Lexan substrates are being produced as transfer standards to allow laser and broadband transmittance measurements to be directly compared. Transmittance measurements performed at NIST have been used to aid Luxel in the modeling and development of various metallic coatings used in the filters. Luxel's work has been partially funded by an SBIR Phase I grant, which has been extended to Phase II this year.

■ **Nichols Research Corporation.** An LBIR User Board had been setup several years ago with Milt Triplett of Nichols Research as the chairman. The board has been meeting two times a year to coordinate NIST IR calibration and standards development program to address the needs of the IR user community. A user board meeting was held in May 1996, in conjunction with The Sixth IR Sensor Calibration Symposium at Logan, Utah.

■ **Sverdrup Technology (Arnold Engineering Development Center).** Steven Lorentz supplied BIB detectors that were designed by NIST to serve as transfer standards at AEDC. The staff of Sverdrup Technology at AEDC will use them for internal consistency checks in various test chambers. Calibrated BIB detectors will be supplied to them in near future.

■ **Space Dynamics Laboratory (SDL).** Optical technology division at NIST sponsored the Sixth IR sensor calibration symposium in May 1996 and several NIST researchers have presented poster papers and invited talks. They have been working with SDL staff in proposing space based calibrations using MIR, the future American Space station, and space shuttle flights where applicable.

■ **MIT Lincoln Laboratory.** Alan Pine initiated a contract with MIT Lincoln Laboratory to develop GaAs photo mixers that would be more efficient and generate THz radiation at higher frequencies than those available presently. This would improve the technology for generating long wavelength IR.

■ **Naval Research Laboratory (NRL).** The development of instrumentation, materials and methodologies for diffuse reflectance has been conducted by Leonard Hanssen in cooperation with Dr. Keith Snail at NRL. Based on the collaborative work, a book chapter on diffuse reflectance measurement has been written.

■ **Optical Metrology for Photolithography.** The Division is a key participant in an extensive collaborative effort with several NIST laboratories, SEMATECH, and MIT Lincoln labs to develop metrology needed for emerging UV photolithography technology. The divisions' effort focuses on measurements of optical properties of candidate lens materials.

IONIZING RADIATION DIVISION (846)

■ **Methods to Calibrate and Characterize Beta-Particle Brachytherapy Sources.** C.G. Soares is working with Novoste Corp. of Atlanta, Neo-Cardia Corp. of Lake Charles, LA, and Isotopen-Technik of Germany to develop methods to calibrate and characterize intravascular brachytherapy sources for use in preventing restenosis after angioplasty therapy. The procedure of angioplasty is performed over 300,000 times in the U.S. each year, and in about 40% of the cases, restenosis occurs, requiring another treatment. Research has shown that a dose of about 10 Gy, delivered to the wall of the blood vessel after the angioplasty has been performed, is effective in inhibiting restenosis. NIST has taken an early and leading role in developing methods for the calibration of the sources used for this therapy, employing the NIST extrapolation chamber and radiochromic dye film.

■ **Methods to Characterize ^{204}Tl Sources for Proficiency Testing.** C.G. Soares is working with the University of Michigan on a comparison of ^{204}Tl sources used to irradiate passive dosimeters for proficiency testing. Discrepancies have been noted in responses to dosimeters irradiated to various ^{204}Tl sources. These sources all pass the criteria established by the ISO, DoE, and ANSI, and work is underway to investigate the reasons for the different responses. It is anticipated that this work will lead to better criteria to characterize such low energy sources.

■ **Radiation Treatment of Blood Prior to Transfusion.** The American Association of Blood Banks considers the irradiation of blood an important factor in the prevention of transfusion associated graft-versus-host disease (GVHD). In a collaboration between NIST and Nordion International, Inc., it has been demonstrated that by means of accurate absorbed-dose measurements on the product, or in simulated products, that the specified absorbed-dose range can be achieved. With the increasing regulatory requirement for dosimetry, a number of dosimetry services have become available in the blood irradiation absorbed-dose range (1500 cGy to 5000 cGy), where gamma-ray sources are used. Validation procedures give standardized results when calibrated dosimeters are mailed to the blood bank for irradiation, and back to the laboratory for analysis. Reference standard dosimeters are used to measure the absorbed-dose rate at a reference point withing, or on blood or blood-equivalent medium. That measurement is used to calculate the timer setting required to deliver the specified dose to the center of the blood product. Dose mapping in real or simulated product, using routine dosimeters, helps to establish the relationship between the maximum and minimum absorbed dose and the targeted central dose. Mapping, an integral part of a measurement quality assurance program, helps to ensure that the specified absorbed-dose distribution within the blood has been achieved.

■ **Real-time Solid-state Detector for On-line Radiation Processing.** S.M. Seltzer and W.L. McLaughlin are collaborating with researchers from Medpack, Inc., and Trygon, Inc., on the development and refinement of real-time dose monitoring techniques of high-powered, low-energy electron accelerators used in industrial radiation processing. The system is based on an electronic monitoring system that records several process variables related to the electron beam irradiation. Bremsstrahlung from the passage of the electron beam through the accelerator beam window is used to monitor the intensity, and thus dose, of the beam. A monitoring system of this type would greatly contribute to the goal of parametric release of irradiated product, as all process variables could be measured and evaluated in real-time. Such a development would allow more efficient use of the irradiators, which are used to sterilize medical products, crosslink polymeric materials, and cure coatings.

■ **Electron Transport Calculations for CT X-Ray Tube Design.** Monte Carlo calculations were done to provide Teledyne Electronic Technologies with information on the number, energy and angular distribution of electrons backscattered from the anode for their development of an x-ray tube with long duty cycle, suitable for extended routine use in spiral computed tomography systems. The new design relies on a novel heat removal system for the anode, but the backscattered electrons need to be understood so that measures can be taken to prevent heating of the tube envelope. Calculations were done for the geometry corresponding to the tube parameters and for bombarding electron beams with energies from 80 keV to 140 keV.

■ **Calculations of 450 kVp X-Ray Spectra.** GE Corporate Research and GE Aircraft Engines are part of an ATP project for "Fast Volumetric

X-Ray Scanner for Three Dimensional Characterization of Critical Objects" in the motor vehicle manufacturing technology category. Their initial detector and system simulation depends on knowledge of the x-ray spectrum produced by their 450 kVp x-ray generator. The results of extensive Monte Carlo calculations were provided to characterize the spectrum at the location of the proposed sensor plane and the spectral variations over the sensor area.

■ **Development of Very Low-Level Standards for Estimation of Microchip Breakdown Rates.** Dow Chemical Company has developed a new technique for providing ultradense microchips. An old problem has resurfaced, namely, electrical breakdown can occur when an impurity alpha particle intrudes and deposits a significant amount of charge. NIST is helping with the problem by developing ultra-low-level standards for the testing of polymeric materials used for the construction of the chips.

■ **Glow-Discharge Resonance Ionization Spectroscopy Investigations.** J.M.R. Hutchinson and collaborators in the Analytical Mass Spectrometry Group, Franklin & Marshall College, and Eastern Analytical Company have installed 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 prior to measurement.

■ **Industrial Quality, Inc.** Harold Berger of Industrial Quality, Inc., Gaithersburg, collaborates with the Neutron Interactions and Dosimetry Group on neutron radiography and non-destructive analysis for hydrogen in metals. NIST provides a ^{252}Cf neutron field to Berger and his collaborators at the University of Virginia for high energy neutron radiography; Berger provides industrial samples of interest for hydrogen-in-metals analysis and expertise in neutron radiography to NIST.

■ **EXXON Research Engineering.** M. Arif is working with the EXXON Corporate Research Science Laboratory on neutron imaging of hydrogen distribution in a polymer electrolyte fuel cell.

TIME AND FREQUENCY DIVISION (847)

■ **Two-Way Timing in SONET Systems.** Marc Weiss and Steve Jefferts are collaborating with Telecom Solutions, Inc. on the use of two-way-time-transfer methods for synchronizing telecommunications nodes with very high precision.

QUANTUM PHYSICS DIVISION (848)

■ **Laser Flux Monitoring System.** A program will be developed in a partnership between S. Leone of the Quantum Physics Division and SVT Associates of Minneapolis, MN, to research, construct and test a laser flux monitoring system for molecular beam epitaxial growth. This joint effort, which is supported under the ARPA Ultra Program, will address the long-standing need for accurate flux monitoring of all species during growth.

■ **Near Field Scanning Optical Microscopy.** S.R. Leone collaborates with Perdix, Inc. on the development of novel tip designs containing nonlinear optical materials for near field scanning optical microscopy.

■ **Neutral Stream Etching.** S.R. Leone is a member of the SEMATECH working group on Neutral Stream Etching, to develop a new generation of etching devices that eliminate the damaging properties of ions in plasma sources.

■ **Real Time Monitoring of Anaesthetic.** S.R. Leone and W.C. Lineberger worked with representatives from Ohmeda to develop a gas calibration system real time monitoring of anaesthetic used in hospitals agents.

■ **Industry at JILA Program.** JILA conducts an "Industry at JILA" visitor series. The goals are:

- broaden the perspective of our science graduate students in the direction of industry so they can consider industry careers from an informed perspective;
- make our senior scientists more familiar with technology problems of interest to U.S. companies; and
- introduce senior industry scientists to our world-class technology, facilities, staff, and students as a prelude to possible long-term research relationships. Each one-day visit includes a discussion of current technical problems facing a particular industry, meetings with individual JILA staff members and students, tours of laboratory and shop facilities, and an informal lunch discussion reserved for students. During the past two years visitors in this series have included:

Dr. R. Teets, Physics Department, General Motors R&D Center, Warren, MI, January 1995.

Dr. Richard Freeman, Head, Advanced Lithography Group, AT&T Bell Labs, Holmdel, NJ, March 1995.

Dr. F. Houle, Lithography Group, IBM Almaden Research Center, San Jose, CA, March 1995.

Mr. P.M. Baker, Executive Director, Laser Institute of America, Orlando, FL, April 1995.

Dr. Milton Chang, President, NewFocus Corp., Sunnyvale, CA, July 1995.

Dr. C. Zanoni, Vice President for Research, Zygo Corporation, Middlefield, CT, September 1995.

Bob Jordan, Gravimetry Group, Allied Signal Aerospace, Redmond, WA, October 1995.

Dr. T. Baur, President, and Greg Kopp, Senior Scientist, Meadowlark Optics, Longmont, CO, November 1995.

Dr. W. Rogers, Research Group Leader, E.I. DuPont de Nemours and Company, Wilmington, DE, February 1996.

Willes Weber, Principal Research Scientist, Ford Motor Company, Dearborn, MI, April 1996.

Dr. D. Baney, Hewlett Packard Research Labs, Palo Alto, CA, May 1996.

Dr. T. Day, Vice Pesident for Research, NewFocus Corp., Santa Clara, CA, visited July 22 to August 1, 1996.

Dr. N. Dodge, University Relations, Texas Instruments Corp., Dallas, TX, September 1996.

Dr. P. Strupp and Dr. R. Chesnut, Quantum Corporation, Louisville, CO, November 1996.

Dr. E. Pitcher, Silicon Graphics/Cray Research, December 1996. ▫

APPENDIX G

OTHER AGENCY RESEARCH AND CONSULTING

G

OTHER AGENCY RESEARCH AND CONSULTING

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

L.R. Canfield and R.E. Vest assisted personnel from the University of Southern California and NOAA in the calibration of extreme ultraviolet flux monitors.

C.W. Clark, research for National Science Foundation through the University of Maryland: quantitative modelling of atomic Bose-Einstein condensates.

J.J. McClelland and R.J. Celotta, research for NSF through Harvard University and the Consortium for Light Force Dynamics: laser focusing of atoms for nanostructure fabrication and microlithography by exposure of self-assembled monolayers to metastable rare gas atoms.

D.T. Pierce and R.J. Celotta, research for ONR: Magnetism in Low Dimensional Systems to make measurements to determine the role that physical and magnetic microstructure plays in determining macroscopic properties.

ATOMIC PHYSICS DIVISION (842)

G.W. Bryant, research for Army Research Laboratory: Modeling and simulation of guide/anti-guide semiconductor structures to implement self-imaging waveguide beam-splitters.

P. Julienne, recipient of Army Research Office grant, subcontracted from the University of Maryland, for research on the theory of atomic collisions in ultracold atom traps.

Y.-K. Kim, recipient of a Department of Energy contract to provide electron-impact ionization cross sections to the magnetic fusion research community.

Y.-K. Kim, recipient of a NASA contract to provide high-precision oscillator strengths of atoms and ions for the astrophysics research community.

W.C. Martin, research for NASA: Critical compilations of atomic spectroscopic data needed for space astrophysics.

W.C. Martin and W.L. Wiese, research for NASA: Building of an atomic spectroscopic database needed for space astronomy.

W.C. Martin, research for DOE: Critical compilations of atomic spectroscopic data of magnetic-fusion interest.

F.H. Mies, research for NATO (International Collaboration Grant): Collisions of Ultracold Hydrogen Atoms in Intense Laser Fields.

F.H. Mies, research for NIST-India Cooperative Research Program: Photodissociation of Molecules in Intense Laser Fields.

P.J. Mohr, Grant from NATO: Research Grant on applications of QED theory with Professor G. Soff of Germany.

W.D. Phillips, research for the Office of Naval Research: Laser cooling and electromagnetic trapping of neutral atoms.

W.D. Phillips, for Harvard University: Manipulation of Matter with Light.

J. Reader, research for DOE: Spectroscopy of highly ionized atoms to obtain data needed for diagnostics of magnetic-fusion plasmas.

J. Reader and C.J. Sansonetti, research for NASA: Wavelengths and isotope shifts for Hg II, Zr III, Di II, III, Pb III.

J. Roberts, research for SEMATECH: Ultraviolet irradiance measurement technology for Deep Ultraviolet photolithography.

W.L. Wiese (Principal Investigator), research for the Fusion Energy Office, DOE: Determination of atomic data for the fusion energy program. This is a 4-component program, covering experimental and theoretical work on spectroscopy and collision physics in the Atomic Physics Division and at JILA, including the above mentioned research by J. Reader, W.C. Martin and Y.-K. Kim.

W.L. Wiese, research for NASA: Critical evaluation and compilation of transition probability data pertinent to the space astronomy program.

OPTICAL TECHNOLOGY DIVISION (844)

C. Asmail and T. Germer, research for the U.S. Air Force CCG: Development of goniometric optical scatter instrument.

C. Asmail and T. Germer, research for General Electric Corporation: Bidirectional Reflectance Distribution Function (BRDF) measurements.

C. Asmail and T. Germer, research for Physical Optics Corporation: Bidirectional Reflectance Distribution Function (BRDF) measurements.

M.P. Casassa, D.F. Plusquellic, and J.C. Stephenson, research for AFOSR: Molecular dynamics measurements of near-threshold reactions of $O(^3P)$ with H_2, H_2O, and HCN to obtain data needed for modeling chemistry in the upper atmosphere, orbital environments, combustion, and propulsion systems.

R. Datla, S. Lorentz, C. Johnson, J. Rice, and R. Saunders, research for U.S. Air Force CCG: Medium background IB (MBIR) metrology.

R. Datla, S. Lorentz, and L. Hanssen, research for U.S. Air Force CCG: Infrared spectral emmittance.

D. Dummer, L. Hanssen and R. Datla, research for U.S. Navy CCG: Infrared polarization standards and metrology.

G. Eppeldauer and A. Migdall developed and delivered to Los Alamos National Laboratory a transfer standard cryogenic bolometer. The high sensitivity bolometer was calibrated for absolute spectral responsivity in the 2 μm to 15 μm wavelength range.

G. Eppeldauer and C. Cromer, research for U.S. Air Force CCG: Development of radiance and irradiance infrared transfer standard radiometers.

G. Eppeldauer and C. Cromer, research for U.S. Navy CCG: Calibration of night vision detectors.

G.T. Fraser and J.T. Hougen, research support from NASA Upper Atmosphere Research Program for "Infrared Spectroscopy Studies on Atomposhpere Molecules."

T. Germer and C. Asmail, research for OSMP in collaboration with MIT Lincoln Laboratories: Quality assessment for fused silica optics in 193 nm lithography steppers.

L. Hanssen, F. Dunmore, S. Kaplan, and R. Datla, research for U.S. Air Force CCG: Filter out-of-band blocking.

L. Hanssen, A. Migdall, A. Pine, S. Kaplan, and R. Datla, research for U.S. Air Force CCG: Infrared spectral transmittance.

L. Hanssen, A. Pine, and R. Datla, research for U.S. Air Force CCG: Spatial uniformity of filters.

L. Hanssen and C. Zhu, research for U.S. Army CCG: Non-linearities in infrared fourier transform spectroscopy.

E.J. Heilweil, research collaboration with Dr. Neil Lewis, Division of Chemical Physics, NIH to design and test a step-scan FTIR confocal microscope coupled to an MCT focal plane array detector for mid-infrared spectral imaging.

J.T. Hougen, researcher for DoE grant "Spectroscopic Investigation of the Vibrational Quasi-Continuum Arising from Internal Rotation of a Methyl Group."

C. Johnson, L. Hanssen, and G. Eppeldauer, researchers for U.S. Air Force, CCG: Rapid blackbody calibrator.

C. Johnson and R. Saunders, research for U.S. Air Force CCG: Infrared target simulator calibration.

S. Lorentz and R. Datla, research for U.S. Air Force CCG: Infrared detector transfer standards.

S. Lorentz and R. Datla, research for U.S. Air Force CCG: Improved absolute cryogenic radiometer for the LBIR facility

Y. Ohno, research for Federal Aviation Administration: Development of Flashing Light Standards. The goal of the project is to establish NIST flash flashing light standards and to develop capability at NIST to calibrate photometers for aircraft anticollision lights.

Y. Ohno, C. Cromer, and G. Eppeldauer, research for U.S. Air Force CCG: Photometric standards and procedures.

A.S. Pine, researcher for NASA Upper Atmosphere Research Program Contract #W-18,249 on "Collisional Lineshapes 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.

R. Saunders and D. Dummer, research for U.S. Air Force CCG: Infrared transmittance and specular reflectance standards.

IONIZING RADIATION DIVISION (846)

J. Adams and D.M. Gilliam, consultants to the Nuclear Regulatory Commission: Research on regulatory guide for neutron dosimetry measurements and calculations for reactor pressure vessels.

J. Adams and A.K. Thompson, research for the U.S. Army Pulse Radiation Facility, Aberdeen Proving Ground: Test of electronic damage surveillance dosimetry using ^{252}Cf neutron irradiations at NIST.

R. Collé, through an interagency agreement between the NIST Radioactivity Group and the U.S. Environmental Protection Agency (EPA): Provide technical assistance to EPA in designing and constructing a primary radon calibration system at its Las Vegas laboratory.

M.S. Dewey and D.M. Gilliam, research for the DoE: Fundamental physics with cold neutrons; the neutron lifetime, ultracold neutrons, decay correlation coefficients, production of polarized neutrons, determination of neutron flux, parity non-conserving spin rotation.

T. Gentile and A. Thompson, research for the DoE as subcontractor to Indiana University: Neutron polarizers based on polarized ^{3}He, metastability-exchange, magnetic field-free compression, spin exchange, cell development.

J.M.R. Hutchinson and M.P. Unterweger with support from the U.S. Army: Perform traceability testing of U.S. Army primary standards laboratory.

J.M.R. Hutchinson and M.P. Unterweger with support from the U.S. Army: Perform traceability testing of the U.S. Army field testing program.

J.M.R. Hutchinson and M.P. Unterweger with support from the U.S. Air Force: Provide measurements and calculations that determine the 2π to activity ratios for beta particles emitted from arbitrarily thick sources plated on substrates of arbitrary atomic number.

J.M.R. Hutchinson and M.P. Unterweger with support from the U.S. Air Force: Provide traceability measurements and techniques assessments for the U.S. Air Force primary laboratory.

J.M.R. Hutchinson *et al.*, with support from the Environmental Protection Agency (EPA): Provide measurements' intercomparisons with the EPA's primary radon laboratories.

J.M.R. Hutchinson and J.T. Cessna, with support from the Environmental Protection Agency: Provide traceability testing of the EPA primary standards laboratory.

J.M.R. Hutchinson and L.L. Lucas, with support from the Nuclear Regulatory Commission: Provide traceability testing of the NRC primary quality control laboratory.

J.M.R. Hutchinson *et al.*, with support from the NEI and the Food and Drug Administration (FDA): Provide standards and calibrations for the primary standards laboratory of the FDA.

K.G.W. Inn, with support from DoE's Radiological and Environmental Sciences Laboratory, Idaho Falls: Provide radiochemistry quality assurance by improving the traceability and strengthening the credibility of their Radiobioassay Laboratory Accreditation Program.

K.G.W. Inn, with support from the Department of Energy: Radiochemistry quality assurance to evaluate the state-of-the-art of ^{239}Pu in urine by inductively coupled plasma mass spectrometry and fission track analysis.

P.J. Lamperti, with support from the Federal Emergency Management Agency: Provide x-ray and gamma-ray calibrations for FEMA's laboratory radiation standards.

C.M. O'Brien and P.J. Lamperti, with support from the Food and Drug Administration: Established national standards and a facility to provide air-kerma (exposure) calibrations for mammography x-ray beams.

S.M. Seltzer, C.M. O'Brien and J.H. Sparrow, with support from the Department of Energy: Spectral measurements of the x-ray beam qualities used at NIST to provide air-kerma standards and calibrations.

C.G. Soares: Work with Brookhaven National Laboratory on hot-particle dose assessment.

C.G. Soares, P.J. Lamperti and J.T. Weaver, with support from the Department of Energy: Installation and characterization of ISO x-ray beam qualities at NIST to provide for harmonization of U.S. and international air-kerma standards and calibrations for radiation protection.

J.H. Sparrow, with support from the Department of the Navy: Perform calibrations and provide image interpretations and consulting for the radiography and high-energy x-ray CT systems used to inspect missile rocket engine assemblies.

J.H. Sparrow and S.M. Seltzer, with support from the National Institute of Dental Research: Participate in the development of a novel tomosynthetic radiographic system to provide tomographic images for dental applications.

J.T. Weaver, with support from the Department of the Navy: Perform irradiations of TLD badges for proficiency testing of Navy's personnel dosimetry program.

J.T. Weaver, J. Shobe and S.M. Seltzer, with support from the Department of the Navy: Calibrate and characterize the ^{137}Cs sources used in the Navy personnel dosimetry calibrations program.

TIME AND FREQUENCY DIVISION (847)

R.E. Drullinger, consulting to the U.S. Air Force (Space Division); Basic research on the physics of atomic standards.

R.E. Drullinger, consulting to the Westinghouse Corporation; consultation on the joint Westinghouse - DARPA Atomic Clock Project.

R.E. Drullinger, consulting and delivery of a primary frequency standard for the Japan National Standards Laboratory.

K.M. Evenson, Research for the Astrophysics Laboratory of NASA: Far infrared spectroscopy of atmospheric and space studies.

K.M. Evenson, Research for the Smithsonian Astrophysics Laboratory: Far infrared spectroscopy of atmospheric and space studies.

K.M. Evenson, Research for the office of Space Sciences, U.S. Air Force: Research and consultation on planar antennas and diodes for solar radiation.

D.W. Hanson, consulting to National Weather Service, NOAA. Broadcast of marine weather alerts on WWV and WWVH.

D.W. Hanson, consulting to the U.S. Coast Guard (Department of Transportation). Broadcast of status of GPS satellites on WWV and WWVH.

J.A. Levine, D.W. Hanson, Research and consulting for the Naval Research Laboratory: Support of NRL Ensemble and Two-way time transfer projects.

T.E. Parker, Research and consulting for Space Division, U.S. Air Force: Analysis of GPS data and systems and consultations on GPS operating procedures.

T.E. Parker, Consulting for the Jet Propulsion Laboratory, NASA: Time transfer to NASA sites and analysis of time transfer data.

F.L. Walls, Research and consulting for guidance and metrology center, U.S. Air Force. Development of a phase noise measurement standard.

F.L. Walls, Research and development of a pulsed phase noise measurement standard for the Office of Naval Research (ONR).

F.L. Walls, Research for Ft. Monmouth (U.S. Army). Development of phase noise artifacts as transfer standards.

F.L. Walls, Research for Ft. Monmouth (U.S. Army). Development of phase noise test sets for PM Milstar project.

D.J. Wineland, consulting to Office of Naval Research (ONR): Basic research on frequency standards and study of cooled, trapped ions.

D.J. Wineland, consulting to Office of Naval Research (ONR): Research into strongly-coupled, one-component plasmas stored in electromagnetic traps.

D.J. Wineland, consulting to the Department of the Army: Research on quantum measurement with correlated atoms.

D.J. Wineland, consulting to the National Security Agency (NSA): Research on quantum computing.

QUANTUM PHYSICS DIVISION (848)

P.L. Bender, research for NASA: Laser Interferometer Space Antenna (LISA) Studies.

P.L. Bender, research for NASA: Event Rate for LISA Gravitational Wave Signals from Black Hole-massive Black Hole Coalescences.

P.L. Bender, research for NSF: Low Frequency Isolation Systems for Gravitational Wave Interferometers.

T. Clement, research for NIST: Optical Physics Applications.

T. Clement, research for NSF(GG)*: Research in Atomic and Molecular Physics.

E.A. Cornell, research for ONR: Optical Refrigeration in the Solid State.

E.A. Cornell, research for NSF (GG)*: Research in Atomic and Molecular Physics.

E.A. Cornell, research for ONR: Spontaneous Force Optical Traps.

E.A. Cornell, research for ONR: Neutral Atoms Hoses and Waveguides.

G.H. Dunn, research for DOE: Determination of 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: Borehole Gravity Senior Development.

J.E. Faller, research for NASA: Relativity Parameters.

J.E. Faller, research for NSF: Active, Low-Frequency Vibration Isolation system."

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.C. Gallagher, research for NREL: Growth Mechanisms and Characterization of Hydrogenated Amorphous Silicon Alloy Films.

A.C. Gallagher, research for NSF (GG)*: Research in Atomic and Molecular Physics.

J.L. Hall, research for AFOSR: Optical Frequency Standards, Diode Lasers, and Precision 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.

J.L. Hall, research for NIST: Laser Frequency Control.

S.R. Leone, research for ACS/PRF: Laser Probing of III-V Growth.

S.R. Leone, research for AFOSR: Theoretical/Experimental Investigations of the Structure and Dynamics of Highly Energetic Dication Species.

S.R. Leone, research for AF/AASERT: Reactions of Atmospheric Cluster Ions.

S.R. Leone, research for AFOSR: State-Resolved Dynamics of Ion-Molecule Collisions in a Flowing Afterglow.

S.R. Leone, research for ARO: Anistropy of Etching Profiles by Translationally Fast Chlorine Molecules.

S.R. Leone, research for ARO: Surface Deposition and Etching Interactions of Laser-Generated Translationally Hot Atoms and Radicals.

S.R. Leone, research for ARO: Mechanisms of Semiconductor Dry Etching by Translationally Hot Atoms and Molecules.

S.R. Leone, research for ARO: Ultrafast Near Field Optical Microscopy of Semiconductor Materials.

S.R. Leone, research for DOE: Time-resolved FTIR Emission Studies of Laser Photofragmentation and Radical Reactions.

S.R. Leone, research for NASA: Laboratory Studies of Low Temperature Rate Coefficients: The Atmospheric Chemistry of the Outer Planets.

S.R. Leone, research for NASA: Laboratory Infrared Emission Studies of Interstellar Molecules: Polycyclic Aromatic Hydrocarbons and Related Species.

S.R. Leone, research for NSF: Kinetic Energy Enhanced Neutral Beam Epitaxy.

S.R. Leone, research for NSF: State and Alignment Resolved Molecular Dynamics.

S.R. Leone, research for NSF (GG)*: Research in Atomic and Molecular Physics.

S.R. Leone, research for NATO: Collisional Vector Correlations with Analysis of Coherence Terms.

S.R. Leone, research for AFOSR: Ultra-Sensitive Laser Ionization for Real Time Analysis-Control.

J.L. Linsky, research for NASA: Instrumental Definition Team for the Far Ultraviolet Spectrograph Explorer satellite.

J.L. Linsky, research for NASA: Studies of Stellar Chromospheres, Winds, and the Deuterium Abundance of the Universe using the Hubble Space Telescope (HST) (6 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 (2 individual grants).

J.L. Linsky, research for NASA: Studies of X-ray Emission from Stellar Coronae using the ROSAT Satellite (5 individual grants).

J.L. Linsky, research for NASA: Studies of X-ray Emission from Stellar Coronae using the ASCA Satellite (3 individual grants).

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 NSF: U.S.-Australia Cooperative research on Stellar Radio Emission.

D.J. Nesbitt, research for AFOSR: State-to-State Reactive Collisional Dynamics of Atmospheric Species.

D.J. Nesbitt, research for AFOSR: Direct Absorption Laser Studies of Spectroscopy, Kinetics and State-to-state Collisional Dynamics of Atmospheric IR Emitters.

D.J. Nesbitt, research for NASA: Time Resolved Studies of HO_2 + OH Kinetics of Relevance to Atmospheric Modeling.

D.J. Nesbitt, research for NSF: Direct IR Laser and Double Resonance Absorption Spectroscopy in Slit Supersonic Jets: Vibrational Dynamics of Novel Molecular Clusters.

D.J. Nesbitt, research for NSF (GG)*: Research in Atomic and Molecular Physics.

D.J. Nesbitt, research for NATO: Collaborative Theoretical Experimental Studies of Cluster Dynamics with David Clary at University of Cambridge.

D.J. Nesbitt, research for Israel-U.S. Binational Science Foundation: Collaborative Theoretical/experimental Studies of Gas-solid Collision Dynamics with Berry Gerber at Hebrew University.

D.J. Nesbitt, research for Outreach Council: CU Wizard Science Outreach.

P.L. Bender, research for NASA: Laser Interferometer Space Antenna (LISA) Studies.

*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 – 1995

TYPE OF SERVICE	Customer	SP 250	No. of Tests	Income
Far UV Detector	Univ. of California at Berkeley Smithsonian Astrophysical Obs.	40510C	2	4.3K
Far UV Detector	Spire Corp. Holonix Corp.	40511C	2	6.3K
Far UV Detector	Univ. of Colorado	40530C	1	1.8K
Far UV Detector	Johns Hopkins Univ. Smithsonian Astrophysical Obs.	40531C	2	3K
Far UV Detector	Univ. of Colorado Smithsonian Astrophysical Obs. Univ. of California at Berkeley	40560C	2	19K
Far UV Detector	Universal Spectrum Corp. Smithsonian Astrophysical Obs. Univ. of California at Berkeley EMR Photoelectric Johns Hopkins Univ. Martin Marietta Universal Spectrum Corp. Univ. of Wisconsin	40561C	8	11.1K
Far UV Detector	Univ. of California at Berkeley Ball Aerospace GE Research Goddard Space Flt. Ctr. Intl. Rad. Detectors Sandia Nat. Lab.	40599S	12	15.7K

ELECTRON AND OPTICAL PHYSICS DIVISION (841) (Cont'd)

CALIBRATION SERVICES PERFORMED – 1996

TYPE OF SERVICE	Customer	SP 250	No. of Tests	Income
Far UV Detector	Paul Scerrer Institut Bechtel Nevada Univ. of California at Berkeley	40510C	4	15.8K
Far UV Detector	VWR Scientific	40530C	1	1.9K
Far UV Detector	Smithsonian Astro. Obs.	40531C	2	3.1K
Far UV Detector	Univ. of California at Berkeley	40560C	1	9.6K
Far UV Detector	Universal Spectrum Corp. Smithsonian Astro. Obs. Univ. of California at Berkeley EMR Photoelectric	40561C	5	7.7K
Far UV Detector	Boston Univ. Sandia Nat. Lab. Phys. Tech. Stud. Goddard Space Flt. Ctr. Smithsonian Astro. Obs. Lawrence Berkeley Lab. Ushio America Skytek Corp. Jet Propulsion Lab. Bechtel Nevada Naval Res. Lab. Rutherford Appleton Lab. Osram Sylvania	40599S	23	55.2K

ELECTRON AND OPTICAL PHYSICS DIVISION (841) (Cont'd)

CALIBRATION SERVICES PERFORMED AT THE SURF II SPECTROMETER CALIBRATION FACILITY – 1995/1996

TYPE OF SERVICE	Customer	Instrument	No. of Tests
Spectrometer	Naval Research Laboratory	SUSIM-ATLAS-3 Solar Ultraviolet Spectral Irradiance Monitor for the third mission of the Atmospheric Laboratory for Applications and Science	1
Spectrometer	NASA Goddard Space Flight Center	Solar EUV Rocket Telescope & Spectrograph Grating Chamber for spatially-resolved solar emission lines	6
Spectrometer	National Center for Atmospheric Research High Altitude Observatory	EUV Grating Spectrometer for measuring solar EUV irradiance	1
Spectrometer	NIST	Dual-Grating Monochromator for calibration of in-house standard photodiodes	4
Spectrometer	Lawrence Livermore National Laboratory	Diverter SPRED Spectrometer used to characterize impurities and impurity transport in fusion experiments on the DIIID Tokamak in San Diego, CA	3
Spectrometer	University of Southern California Space Sciences Center	Solar EUV Monitor 2 for studying solar helium emission lines	2
Spectrometer	NIST	Irradiance scale intercomparisons	1
Spectrometer	National Center for Atmospheric Research High Altitude Observatory	Calibration and Test Equipment 3 for calibrating XUV imagers to He and H abundances in the solar corona	7

ELECTRON AND OPTICAL PHYSICS DIVISION (841) (Cont'd)

CALIBRATION SERVICES PERFORMED AT THE NIST/ARPA NATIONAL EUV REFLECTOMETRY FACILITY – 1995

TYPE OF SERVICE	Customer	No. of Tests
Optical Components	Osmic LURE (French Synchrotron Facility) NASA Marshall Space Flight Center/Stanford Danish Space Research Institute	23
Multilayer R & D	IBM/Danish Space Research Institute NIST Osmic NASA Goddard Space Flight Center Naval Research Laboratory	63
Thin Film R & D	Aracor	3
Intercomparison	NIST, Lawrence Berkeley Laboratory, Naval Research Laboratory	9
Optical Constants	NIST University of Arizona	2
Magnetic Dichroism	NIST Naval Research Laboratory	10
Grating Efficiency	University of Southern California NASA Goddard Space Flight Center	17
Filter Transmission	NASA Goddard Space Flight Center NASA Marshall Space Flight Center	2
Beamline Polarization	NIST	10
Total		**139**

ELECTRON AND OPTICAL PHYSICS DIVISION (841) (Cont'd)

CALIBRATION SERVICES PERFORMED AT THE NIST/ARPA NATIONAL EUV REFLECTOMETRY FACILITY – 1996

TYPE OF SERVICE	Customer	No. of Tests
Optical Components	Smithsonian Astrophysical Observatory Lawrence Livermore National Lab.	3
Multilayer R & D	NASA Goddard Space Flight Center Osmic	20
Optical Constants	NIST University of Arizona	11
Magnetic Dichroism	Naval Research Laboratory	3
Grating Efficiency	Tulane University NASA Goddard Space Flight Center	1
Filter Transmission	NASA Goddard Space Flight Center	2
Total		**40**

ATOMIC PHYSICS DIVISION (842)

CALIBRATION SERVICES PERFORMED – 1995

TYPE OF SERVICE	Customer	SP 250	No. of Tests	Income
Argon Arc Source	Stanford University	40040S	1	2K
Argon Arc Source	Johns Hopkins Applied Physics Lab	40010C	1	2K
Argon Arc Source	University of Pittsburgh	40020C	1	2K
Argon Arc Source	Ball Aerospace	–	1	2K

CALIBRATION SERVICES PERFORMED – 1996

TYPE OF SERVICE	Customer	SP 250	No. of Tests	Income
Argon Arc Source	University of Wisconsin	–	1	Covered by CRADA
Argon Arc Source	Ball Aerospace	–	1	2.5K

OPTICAL TECHNOLOGY DIVISION (844)

CALIBRATION SERVICES PERFORMED - 1995

TYPE OF SERVICE Customer	SP250		Number of Customers	Number of Tests*	Div. Income
Pyrometry	35010C thru 35070S		19	24	$ 50K
Industry					
Defense & Aerospace		1			
Instrument & Cal labs		6			
Electrical & Materials		7			
Government		5			
Spectroradiometry - Sources	39010C thru 39060S		12	18	$ 81K
Industry					
Instrument & Cal labs		3			
Lighting & Photography		2			
Government		7			
Spectroradiometry - Detectors	39070C thru 39080S		30	44	$ 54K
Industry					
Defense & Aerospace		6			
Instrument & Cal labs		13			
Lighting & Photography		5			
Government		6			
Photometry	37010C thru 37180S		20	29	$ 45K
Industry					
Defense & Aerospace		5			
Lighting & Photography		11			
Government		4			
Spectrophotometry	38010C thru 38100S		19	27	$ 44K
Industry					
Defense & Aerospace		2			
Instrument & Cal labs		7			
Electrical & Materials		10			
			100	142	$ 274K

*Number of lamps, detectors, optical filters or reflectors tested.

OPTICAL TECHNOLOGY DIVISION (844) (Cont'd)

CALIBRATION SERVICES PERFORMED – 1996

TYPE OF SERVICE Customer	SP250	Number of Customers	Number of Tests*	Div. Income
Pyrometry	35010C thru 35070S	19	28	$ 56K
Industry				
Defense & Aerospace		2		
Instrument & Cal labs		4		
Electrical & Materials		5		
Government		8		
Spectroradiometry - Sources	39010C thru 39060S	13	19	$ 66K
Industry				
Defense & Aerospace		3		
Instrument & Cal labs		2		
Lighting & Photography		2		
Government		5		
University		1		
Spectroradiometry - Detectors	39070C thru 39080S	28	49	$ 63K
Industry				
Defense & Aerospace		3		
Instrument & Cal labs		4		
Lighting & Photography		13		
University		8		
Photometry	37010C thru 37180S	28	66	$ 89K
Industry				
Defense & Aerospace		1		
Instrument & Cal labs		4		
Lighting & Photography		18		
Government		5		
Spectrophotometry	38010C thru 38100S	28	36	$ 52K
Industry				
Defense & Aerospace		3		
Instrument & Cal labs		3		
Lighting & Photography		17		
Government		5		
		116	198	$ 326K

*Number of lamps, detectors, optical filters or reflectors tested.

OPTICAL TECHNOLOGY DIVISION (844) (Cont'd)

STANDARD REFERENCE MATERIALS – 1995 and 1996

1. **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.

2. **SRM 2015**, White Opal Glass for directional-Hemispherical Reflectance from 400 nm to 750 nm.

   For use in calibrating the reflectance scale of an integrating sphere reflectometers.

3. **SRM 2003**, First Surface Aluminum Mirror for Specular Reflectance from 250 nm to 2500 nm.

   SRM 2011, First Surface Gold Mirror for Specular Reflectance from 600 nm to 2500 nm.

   SRM 2023, Second Surface Aluminum Mirror for Specular Reflectance from 250 nm to 2500 nm.

   SRM 2026, NG9 Black Glass for Specular Reflectance from 250 nm to 2500 nm.

   For use in calibrating the photometric scale of specular reflectometers.

4. **SRM 1920**, Near Infrared Reflectance Wavelength Standards from 740 nm to 2000 nm.

   For use in calibrating the wavelength scale of reflectance spectrophotometers.

5. **SRM 1931**, Fluorescence Emission Standards for the Visible Region.

   For use in calibrating the relative spectral response of fluorescence spectrometers.

6. **SRM 1921**, Infrared Wavelength Standards from 3 μm to 18 μm.

   For use in calibrating the wavelength scale of infrared spectrometers.

IONIZING RADIATION DIVISION (846)

Radiation Interactions and Dosimetry Group

DOSIMETRY OF X RAYS, GAMMA RAYS, AND ELECTRONS – FY 1995

	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial	A	12	28	38,921
	B	9	37	29,011
	C	1	1	1,089
	D	2	2	7,399
	E	2	5	13,554
	F	4	49	36,585
Medical Facilities	A	1	2	3,024
	F	15	16	23,950
	G	22	57	19,040
Government Agencies	A	9	71	93,448
	F	3	70	7,146
Foreign Laboratories	E	1	2	2,800
	F	2	5	6,460
SUBTOTALS	A	22	101	135,393
	B	9	37	29,011
	C	1	1	1,089
	D	2	2	7,399
	E	3	7	16,354
	F	24	140	74,141
	G	22	57	19,040
GRANDTOTALS	**ABCDEFG**	**83**	**345**	**282,427**

Service Code	Type of Service	SP250 Number
A	X-Ray and Gamma-Ray Measuring Instruments	46010C & 46011C
B	Dosimeter Irradiations	46020C & 46021C
C	Tests of Precision Electrometers	46030S
D	Special Tests	46050S
E	Gamma-Ray Sources	47010C & 47011C
F	Beta-Ray Sources and Measuring Instruments	47030C, 47035C & 47040S
G	High-Energy Electron Beams (Fricke Dosimetry)	48010M & 48011M

IONIZING RADIATION DIVISION (846) (Cont'd)

Radiation Interactions and Dosimetry Group

DOSIMETRY OF X RAYS, GAMMA RAYS, AND ELECTRONS – FY 1996

	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial	A	22	97	129,726
	B	10	36	30,753
	C	1	1	1,163
	D	2	2	8,000
	E	1	2	5,598
	F	3	44	14,699
Medical Facilities	A	4	5	7,501
	C	3	3	3,493
	F	4	5	7,785
	G	20	58	18,192
Government Agencies	A	4	74	83,778
	F	6	6	7,764
Foreign Laboratories	F	1	6	7,764
SUBTOTALS	A	30	176	221,005
	B	10	36	30,753
	C	4	4	4,656
	D	2	2	8,000
	E	1	2	5,598
	F	14	61	38,012
	G	20	58	18,192
GRANDTOTALS	**ABCDEFG**	**81**	**339**	**326,216**

Service Code	Type of Service	SP250 Number
A	X-Ray and Gamma-Ray Measuring Instruments	46010C & 46011C
B	Dosimeter Irradiations	46020C & 46021C
C	Tests of Precision Electrometers	46030S
D	Special Tests	46050S
E	Gamma-Ray Sources	47010C & 47011C
F	Beta-Ray Sources and Measuring Instruments	47030C, 47035C & 47040S
G	High-Energy Electron Beams (Fricke Dosimetry)	48010M & 48011M

IONIZING RADIATION DIVISION (846) (Cont'd)

Radiation Interactions and Dosimetry Group

HIGH-DOSE CALIBRATION SERVICES PERFORMED – FY 1995

Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial:	A	31	185	89,458
medical product sterilization	B	1	1	1,639
Industrial:	A	6	29	14,317
polymer modification	B	2	2	3,351
University:	A	1	3	1,554
	B	1	1	1,624
Foreign Laboratories:	A	1	11	5,357
	B	1	1	1,624
SUBTOTALS:	A	39	228	110,686
	B	5	5	8,238
GRAND TOTALS:	**AB**	**44**	**233**	**118,924**

HIGH-DOSE CALIBRATION SERVICES PERFORMED – FY 1996

Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial:	A	16	105	47,350
medical product sterilization	B	1	2	2,592
	C	1	1	399
Industrial:	A	4	22	8,580
electronic harness testing	B	2	2	2,592
Industrial: polymer modification	A	1	5	2,590
National Laboratories,	B	1	1	1,296
Government Agencies	C	2	2	2,550
Foreign Laboratories:	A	1	11	4,290
	B	1	1	1,296
SUBTOTALS:	A	22	143	62,810
	B	5	6	7,776
	C	3	3	2,949
GRAND TOTALS:	**ABC**	**30**	**152**	**73,535**

Service Code	Type of Service	SP250 Number
A	Dosimeter Calibration	49010C
B	Supply Transfer Dosimeters	49020C & 49030C
C	Special Measurements	49040S & 49050S

IONIZING RADIATION DIVISION (846) (Cont'd)

Neutron Interactions and Dosimetry Group

DOSIMETRY INSTRUMENT AND SOURCE CALIBRATIONS – FY 1995

Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial	H	2	5	12,725
	I	6	14	6,767
Government Agencies	H	3	3	7,635
	I	3	16	3,713
Department of Defense	I	1	1	*
SUBTOTALS:	H	5	8	20,360
	I	10	31	10,480
GRAND TOTALS:	**H,I**	**15**	**39**	**30,840**

DOSIMETRY INSTRUMENT AND SOURCE CALIBRATIONS – FY 1996

Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial	H	4	4	10,180
	I	3	3	1,500
Government Agencies	H	4	4	10,180
	I	3	3	1,500
Department of Defense	H	1	1	2,545
	I	2	2	*
SUBTOTALS:	H	9	9	22,905
	I	8	8	3,000
GRAND TOTALS:	**H,I**	**17**	**17**	**25,905**

*All of these calibrations were done as part of a larger contract and were not billed explicitly.

Service Code	Type of Service	SP250 Number
H	Radioactive Neutron Source Calibration	44010C
I	Neutron Survey Instrument Calibration	44060C

IONIZING RADIATION DIVISION (846) (Cont'd)

Radioactivity Group

RADIOACTIVITY CALIBRATIONS – FY 1995

Catagory	Scheduled Calibrations		Non-Scheduled Tests	
	No. of Sources	Income	No. of Sources	Income
Alpha-particle Sources	27	29,375	15	32,288
Beta-Particle Solutions, Gases, and Solid Sources	4	3,984	3	5,000
Gamma-ray Solutions and Point Sources	–	–	11	14,550
Totals	**31**	**33,359**	**29**	**51,838**

RADIOACTIVITY CALIBRATIONS – FY 1996

Catagory	Scheduled Calibrations		Non-Scheduled Tests	
	No. of Sources	Income	No. of Sources	Income
Alpha-particle Sources	9	9,736	4	4,192
Beta-Particle Solutions, Gases, and Solid Sources	–	–	6	9,732
Gamma-ray Solutions and Solid Sources	1	1,426	10	8,490
Totals	**10**	**11,162**	**20**	**22,414**

IONIZING RADIATION DIVISION (846) (Cont'd)

Radioactivity Group

STANDARD REFERENCE MATERIALS

Radioactivity Standards Issued - FY 1995

SRM	Radionuclide	Principal Calibration Use
4401L-U	Iodine-131	Activity measurement of radiopharmaceuticals
4404L-R	Thallium-201	"
4407L-S	Iodine-125	"
4408L-F	Cobalt-57	"
4410L-T	Technetium-99m	"
4412L-T	Molybdenum-99	"
4415L-S	Xenon-133	"
4416L-P	Gallium-67	"
4417L-O	Indium-111	"
4426L-A	Strontium-89	"
4427L-A	Yttrium-90	"
4234A	Strontium-90	Tracer for radionuclide analysis
4323A	Plutonium-238	"
4324A	Uranium-232	"
4326	Polonium-209	"
4328A	Thorium-229	"
4332D	Americium-243	"
4339A	Radium-228	"
4949C	Iodine-129	"
4203D	Cobalt-60	Gamma-ray spectrometry analysis
4915E	Cobalt-60	"

Total Radioactivity SRMs Distributed: **704**
Gross Sales: **$383,375**

IONIZING RADIATION DIVISION (846) (Cont'd)

Radioactivity Group

STANDARD REFERENCE MATERIALS

Radioactivity Standards Issued - FY 1996

SRM	Radionuclide	Principal Calibration Use
4401L-V	Iodine-131	Activity measurement of radiopharmaceuticals
4404L-S	Thallium-201	"
4406L-N	Phosphorus-32	"
4407L-T	Iodine-125	"
4410L-U	Technetium-99m	"
4412L-U	Molybdenum-99	"
4415L-T	Xenon-133	"
4416L-Q	Gallium-67	"
4417L-P	Indium-111	"
4226C	Nickel-63	Tracer for radionuclide analysis
4320A	Curium-244	"
4328B	Thorium-229	"
4330A	Plutonium-239	"
4334F	Plutonium-242	"
4338A	Plutonium-240	"
4340A	Plutonium-241	"
4233D	Cesium-137	Gamma-ray spectrometry analysis

Total Radioactivity SRMs Distributed: **616**
Gross Sales: **$365,878**

TIME AND FREQUENCY DIVISION (847)

CALIBRATION SERVICES PERFORMED

Note that traceability to NIST and most calibrations are accomplished through direct user 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.		
	1995	1996
Industrial Users:	30	32
Government Users:	19	19
Total service income	$231,000	282,000

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.		
	1995	1996
Industrial Users:	3	2
Scientific Users:	2	2
Foreign Users:	2	3
Total service income	$54,000	53,000

APPENDIX J

ACRONYMS

J

ACRONYMS

AAMI	Association for the Advancement of Medical Instrumentation
AAPM	American Association of Physicists in Medicine
ACR	Absolute Cryogenic Radiometer
ACS	American Chemical Society
ACTS	Automated Computer Time Service
ADCL	Accredited Dosimetry Calibration Laboratories
ADMIT	Analytical Detection Methods for the Irradiation Treatment of foods
AECL	Atomic Energy Canada Limited
AEDC	Arnold Engineering Development Center
AFB	Air Force Base
AFGL	Air Force Geophysics Laboratory
AFM	Atomic Force Microscope
AFOSR	Air Force Office of Scientific Research
AFPL	Air Force Phillips Laboratory
AFRRI	Armed Forces Radiobiology Research Institute
AIGER	American Industry Government Emissions Research Consortium
AI	Associative Ionization
AIAA	American Institute for Aeronautics and Astronautics
AIP	American Institute of Physics
AM1	First Launch in the morning series of EOS platforms
AMMAC	Mexican Metrology Association
AMO	Atomic, Molecular and Optical
AMS	Accelerator-Mass-Spectrometry
ANS	American Nuclear Society
ANSI	American National Standards Institute
ANVIS	Aviator Night Vision Imaging System
APAS	Astrophysical, Planetary and Atmospheric Sciences
APHIS	Animal and Plant Health Inspection Service
APOMA	American Precision Optics Manufacturers Association
APRF	Army Pulse Radiation Facility
APS	American Physical Society
APS	Advanced Photon Source
APT	Annular Proton Telescope
ARO	Army Research Office
ARPES	Angle Resolved Photoelectron Spectroscopy
ASCA	Advanced Satellite for Cosmology & Astrophysics
ASCA	Japan-NASA X-ray Satellite
ASME	American Society for Mechanical Engineers
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
ATP	Advanced Technology Program
ATW	Accelerator Transmutation of Waste
AURA	Association of Universities for Research in Astronomy
AXAF	Advanced X-ray Astrophysical Facility
AXAF-I	Imaging Advanced X-ray Astrophysical Facility
AXAF-S	Spectroscopy 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
BEC	Bose Einstein Condensation
BEEM	Ballistic Electron Emission Spectroscopy
BEV	Bundesamt für Eich-und Vermessungswesen, Vienna, Austria
BFRL	Building & Fire Research Laboratory
BGSM	Bowman Gray School of Medicine
BIB	Blocked Impurity Band
BIPM	Bureau International des Poids et Mésures
BL	Beam Line at SURF-II
BMDO	Ballistic Missile Defense Organization
BNL	Brookhaven National Laboratory
BRDF	Bidirectional Reflectance Distribution Function
BFR	Building & Fire Research Laboratory
BSDF	Bidirectional Scattering Distribution Function
BTI	Bubble Technology, Inc.
CAD	Computer Aided Design
CAM	Computer Aided Machining
CAMOS	Committee on Atomic, Molecular and Optical Sciences
CARB	Center for Advanced Research in Biotechnology
CARS	Coherent Anti-Stokes Raman Spectroscopy
CASS	Calibration Accuracy Support System
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
CCDS	Consultative Committee for the Definition of the Second
CCE	Consultative Committee on Electricity
CCEMRI	Consultative Committee for Ionizing Radiations, CIPM
CCG	Calibration Coordination Group
CCP6	Collaborative Computational Project 6
CCPR	Consultative Committee on Photometry and Radiometry
CDRH	Center for Devices and Radiological Health
CEL	Correlated Emission Laser
CERES	Clouds and Earth's Radiant Energy System
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
CNIF	Californium Neutron Irradiation Facility
CNRF	Cold Neutron Research Facility
CODATA	Committee on Data for Science and Technology
CORM	Council for Optical Radiation Measurements
COSPAR	Committee on Space Research
CPIC	International Physics Center, Elba
CPU	Central Processing Unit
CR	cascaded rectifier accelerator

CRCPD	Conference of Radiation Control Program Directors
CRADA	Cooperative Research and Development Agreement
CRI	Cambridge Research Insturmentation
CRTs	Cathode Ray Tubes
CRYRING	Institute in Stockholm
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
CTI	Critical Technologies Institute
CU	University of Colorado
CVD	Chemical Vapor Deposition
cw	continuous wave
DARPA	Defense Advanced Research Project Agency
DEC	Digital Electronics Corporation
DMA	Defense Mapping Agency
DNA	Defense Nuclear Agency
DNA	Deoxyribose Nucleic Acid
DOC (DoC)	Department of Commerce
DOD (DoD)	Department of Defense
DOE	Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
DORT	Discrete Ordinates Code
DRIP	Detector Response Intercomparison Program
DSA	digital subtraction angiography
DVM	Digital Voltmeter
DUV	Deep-Ultraviolet
EBIS	Electron Beam Ion Source
EBIT	Electron Beam Ion Trap
ec	electron-capture
ECP	Effective Core Potential
ECR	Electron Cyclotron Resonance
ECRIS	Electron-Cyclotron-Resonance Ion Source
ECS	Energy-Corrected-Sudden
ECSED	Electronic Commerce in Scientific and Engineering Data
EDX	Energy-Dispersive X-ray Analysis
EEEL	Electronics & Electrical Engineering Laboratory
EELS	Electron Energy Loss Spectroscopy
EEO	Equal Employment Opportunity
EEP	Einstein Equivalence Principle
EM	Environmental Management
ENEA	Ente Per Le Nuove Tecnologie, L'Energia E L'Ambiente
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
ESA	European Space Agency

ESDIAD	Electron-Stimulated Desorption Ion Angular Distributions
ESO	European Southern Observatory
ESR	Electron Spin Resonance (EPR now preferred)
ESR	Electrical Substitution Radiometer
ESR	Experimental Storage Ring
ETI	environmental technology initiative
ETRAN	Computer Code
EURADOS	European Radiation Dosimetry Group
EUROMET	A European collaboration in measurement standards
EUVE	Extreme Ultraviolet Explorer
EXAFS	Edge X-ray Absorption Fine Structure
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
FEA	Field-Emitter Arrays
FEDS	Field-Emitter Displays
FEL	Free Electron Laser
FEMA	Federal Emergency Management Agency
FET	Field Effect Transistor
FIMS	Fissionable Isotope Mass Standards
FIR	Far Infrared
FLIR	Forward Looking Infrared Radiometer
FNR	Ford Nuclear Reactor
FOS	Faint Object Spectrograph
FOV	Field of View
FT	Fourier Transform
FT-IRAS	Fourier Transform-Infrared Reflection Absorption Spectroscopy
FTIR	Fourier Transform Infrared
FTMS	Fourier Transform Microwave Spectroscopy
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
GEC	Gaseous Electronics Conference
GHRS	Goddard High Resolution Spectrograph
GIM	Grazing-Incidence Monochromator
GINGA	Japanese X-ray Satellite
GOES	Geostationary Operational Environmental Satellite
GPIB	General Purpose Instrumentation Bus
GPS	Global Positioning System
GRI	Gas Research Institute
GRT	Germanium Resistance Thermometers
GSFC	Goddard Space Flight Center
GSI	Gesselschaft für Schwerionenforschung
GVHD	graft-versus host disease

H	Hungary
HACR	High Accuracy Cryogenic Radiometer
HDR	High Dose Rate
HFIR	High Flux Isotope Reactor
HID	High Intensity Discharge
HPLC	high pressure liquid chromatographic
HPS	Health Physics Society
HPSSC	Health Physics Society Standards Committee
HRTS	High Resolution Telescope Spectrograph
HSST	Heavy Section Steel Technology
HST	Hubble Space Telescope
HTD	Heat Transfer Division
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
IDMS	Isotope Dilution Mass Spectrometry
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illumination Engineering Society
IESNA	Illumination Engineering Society of North America
IGC	International Gravity Commission
ILL	Institut Laue Langevin
ILS	International Laser Spectroscopy
IMGC	Istituto di Metrologia "G. Colonnetti" (Italy)
IMS	Institute for Molecular Science
INISO-TTC	experimental radiochromic film
INM	Institute National de Metrologie
INMM	Institute for Nuclear Materials Management
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 Astronomical Satellite
IRAS	Infrared Reflection Absorption Spectroscopy
IRDCF	Infrared Detector Calibration Facility
IRMM	Institute of Reference Materials and Measurements
ISCC	Inter-Society Color Council
ISO	International Organization for Standardization
ISP	International Specialty Products
ISSI	International Space Science Institute (Bern, Switzerland)
ITAMP	International Meeting of Theory of Atomic and Molecular Physics
ITEP	Institute for Theoretical and Experimental Physics
ITER	International Thermonuclear Experimental Reactor
ITS	International Temperature Scale
ITU	International Telecommunication Union
IUCr	International Union of Crystallography

IUE	International Ultraviolet Explorer
IVR	Intramolecular Vibrational Relaxation
IVR	Intramolecular Vibrational Redistribution
IWG	Investigators Working Group
JAERI	Japan Atomic Energy Research Institute
JANNAF	Joint-Army-Navy-Air Force
JCMT	James Clerk Maxwell Telescope
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
LISA	Laser Interferometer Space Antenna
LLNL	Lawrence Livermore National Laboratory
LMR	Laser Magnetic Resonance
LMRI	French Laboratories de Measure des Rayonnements Ionisants
LO	Laser Optics
LORAN-C	A Radio Navigation System Operated by the U.S. Coast Guard
LPRI	Laboratoire Primaire des Rayonnements Ionisants, Gif-sur-Yvette, France
LS	Liquid Scintillation
LSC	liquid scintillation counting
LTE	Local Thermodynamic Equilibrium
LTEC	Lamp Testing Engineers Conference
LTG	Low-temperature-growth
MARLAP	Multi-Agency Radiological Laboratory Procedures
MARS	Multiple-Angle Reference System
MBE	Molecular Beam Epitaxy
MBIR	Medim Background Infrared Facility
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
MEIBEL	Merged Electron-Ion Beam Energy Loss
MEL	Manufacturing Engineering Laboratory
MET	Medium Energy Telescope
MIDAS	Modular Interactive Data Acquisition System
MIL	Military
MIM	Metal-Insulator-Metal (Diode)
MIRD	Medical Internal Radiation Dose (committee)
MIRF	Medical and Industrial Radiation Facility

MISR	Multi-angle Imaging Spectroradiometer
MIT	Massachusetts Institute of Technology
MOBY	Marine Optical Buoy
MOCVD	Metal Organic Chemical Vapor Deposition
MODIL	Manufacturing Operations Development & Integration Laboratory
MODIS	Moderate Resolution Imaging Spectrometer
MOKE	Magneto-Optical Kerr Effect
MOPITT	Measurement of Pollution In The Troposphere
MOS	Metal Oxide Semiconductors
MQDT	Multichannel Quantum Defect Theory
MPD	multiphoton detector
MPI	Multiphoton Ionization
MPP	Multi-Pinned Phasing
MQA	Measurement Quality Assurance
MQDT	Multichannel Quantum Defect Theory
MQSA	Mammography Quality Standards Act
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
NAPM	National Association of Photographic Manufacturers
NAS	National Academy of Sciences
NAS/NRC	National Academy of Sciences/National Research Council
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBS	National Bureau of Standards
NBS-4	Older Primary Frequency Standard (retains NBS name)
NBS-6	Previous Primary Frequency Standard (retains the NBS name)
NBSR	National Bureau of Standards' Reactor (retains the NBS name)
NCAR	National Center for Atmospheric Research
NCI	National Cancer Institute
NCRP	National Council on Radiation Protection and Measurements
NCSCANS	National Steering Committee for the Advanced Neutron Source
NCSL	National Conference of Standards Laboratories
ND	Neutron Density
NDT	Nondestructive Testing
NEANDC	Nuclear Energy Agency Nuclear Data Committee
NEANSC	Nuclear Energy Agency Nuclear Science Committee
NEC	Nippon Electric Corporation
NED	Nuclear Effects Directorate
NEI	Nuclear Energy Institute
NELAC	National Environmental Laboratory Accreditation Conference
NEOS	Newport Electro-Optic Systems
NESDIS	Environmental Satellite Data and Information Service
NEWRAD	New Radiometry
NGS	National Geological Society
NIDR	National Institute of Dental Research
NIH	National Institutes of Health
NIM	Normal-Incidence Monochromator
NIM	National Instrumentation Methods
NIOF	Neutron Interferometry and Optics Facility
NIPDE	National Initiative for Product Data Exchange

NIR	Near Infrared
NIST	National Institute of Standards and Technology
NIST-7	Current Primary Frequency Standard
NML	National Measurement Laboratory (Japan)
NMR	Nuclear Magnetic Resonance
NMS	natural matrix standard
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
NORAMET	A North American regional collaboration in national measurement standards and services
NPL	National Physical Laboratory (U.K.)
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NRL	Naval Research Laboratory
NRLM	National Research Laboratory of Metrology (Japan)
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
NSOM	Near-Field Scanning Optical Microscopy
NVIS	Night Vision Imaging System
NVLAP	National Voluntary Laboratory Accreditation Program
OAI	Optical Associates, Inc.
OCLI	Optical Cooling Laboratory Incorporated
OD	Optical Density
OE	Optical Engineering
OFS	Österreichisches Forschungszentrum
OIML	International Organization of Legal Metrology
OMEGA	24-Beam Laser Facility at Rochester
OMH	National Office of Measures (Hungary)
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
PADE	Parallel Applications Development Environment
PC	Personal Computer
PCB	polychlorinated biphenyls
PDE	Product Data Exchange
PDML	Photovoltaic Device Measurement Laboratory
PECVD	Plasma-enhanced Chemical Vapor Deposition
PET	positron emission tomography

PFID	Perturbed Free Induction Decay
PL	Physics Laboratory
PMG	Precision Measurement Grant
PMMA	polymethylmethacrylate
PMS	Particle Measurement System
PMT	Photomultiplier Tube
PNL	Pacific Northwest Laboratory
POC	Physical Optics Corporation
POPA	Panel on Public Affairs of American Physical Society
PREP	Professional Research Experience Program
PRF	Petroleum Research Fund
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
QA/QC	Quality Assurance/Quality Control
QCD	Quantum Chromodynamics
QED	Quantum Electrodynamics
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
RBS	Rutherford Backscattering
REDA	Resonant-Excitation-Double-Autoionization
REI	Rad Elec, Inc.
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
RTC	Radiochromic Film Task Group
RTP	Rapid Thermal Processing
SBIR	Small Business Innovation Research
SCC	Standards Coordinating Committee
SCLIR	Secondary Calibration Laboratories for Ionizing Radiation
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SDL	Space Dynamics Laboratory
SEAWIFS	Sea-Viewing of Wide Field Sensor (also SeaWiFS
SEBA	Standards' Employees Benefit Association
SEM	Scanning Electron Microscope
SEMATECH	Consortium of 14 U.S. Semiconductor Manufacturers
SEMPA	Scanning Electron Microscopy with Polarization Analysis
SFA	Sachs Freeman and Associates
SFCP	Special Foreign Currency Program
SFG	Sum Frequency Generation

SI	International System of Units
SID	Society for Information Display
SIRREX-3	SeaWifs Intercalibration Round-robin Experiment
SKACR	Superconducting Kinetic-inductance Absolute Cryogenic Radiometer
SLMs	Synthetic Layer Microstructures
SNOM	Scanning Near Field Optical Microscope
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
SSC	Superconductor Super Collider
SSPM	Solid State Photomultipliers
SSRCR	State Suggested Regulations for Controlling Ionizing Radiations
SSTR	Solid State Track Recorder
SSUV	Shuttle Solar Ultraviolet
STARR	Spectral Tri-function automated Reference Reflectometer
STD	Standard
STM	Scanning Tunneling Microscope
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
SVGL	Silicon Valley Group Lithography
SXR	SeaWiFS Transfer Radiometer
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
TLC	thin layer chromatography
TLD	Thermoluminescent Detector
TMA	Tri-methyl-aluminum
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
UCN	ultra cold neutron
UDC	University of the District of Columbia
UHV	Ultrahigh Vacuum
UK	United Kingdom
UPS	Ultraviolet Photoelectron Spectroscopy
URL	Uniform Resource Locator
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
USFDA	U.S. Food and Drug Administration
USGCRP	United States Global Change Research Program
USNA	U.S. Naval Academy
USNC	United States National Committee
USNO	U.S. Naval Observatory
USSR	Union of Soviet Socialist Republics
UTC	Coordinated Universal Time
UV	Ultraviolet
UV-B (UVB)	Ultraviolet-B
VDG	Van de Graaff
VEEL	Vibrational and Electronic Energy Levels
VET	Vibration Energy Transfer
VIS	Visible
VLA	Very Large Array
VLBI	Very Long Baseline Interferometer (or Interferometry)
VNIIFTRI	National Scientific and Russian Research Institute for Physical, Technical and Radiotechnical Measurements
VNIIM	Mendeleyev Institute of Metrology
VNIIOF	All-Union Research Institute for Optical and Physical Measurements
VUV	Vacuum Ultraviolet
WAFAC	Wide-Angle Free-Air Chamber
WERB	Washington Editorial Review Board
WG	Working Group
WHO	World Health Organization
WISE	Women in Science and Engineering
WKB	Wentzel-Kramers-Brillouin
WMO	World Metrological Organization
WSTC	Westinghouse Science and Technology Center
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
WWW	World Wide Web
WYSIWYG	What You See Is What You Get
XANES	X-ray Absorption Near-Edge Structure
XROI	X-Ray Optical Interferometer
XSW	X-ray Standing Wave
XTE/PCA	X-ray Timing Explorer/Proportional Counter Array
XUV	Extreme Ultraviolet
YAG	Yttrium-Aluminum-Garnet