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PHYSICS LABORATORY

Technical Activities 1998

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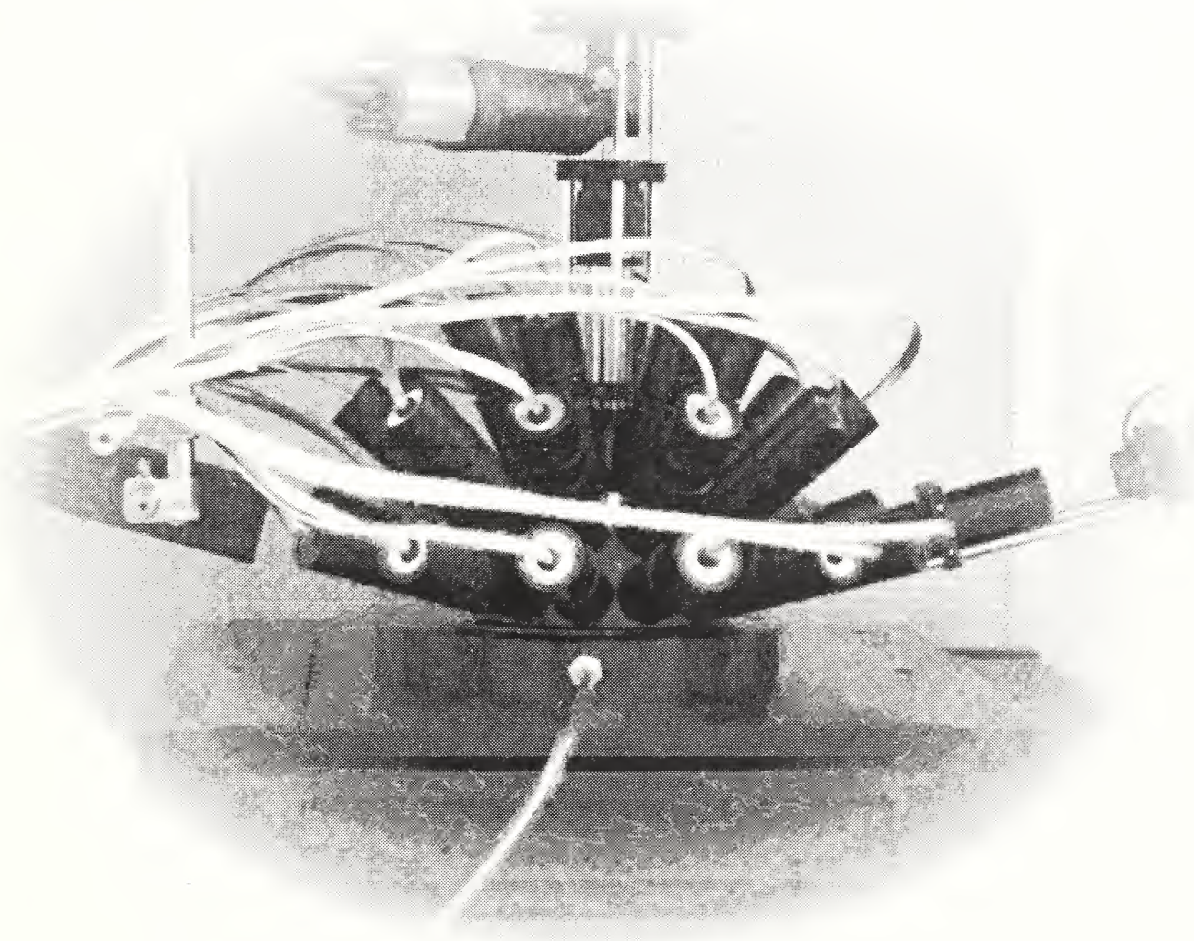

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ABSTRACT

This report summarizes research projects, measurement method developments, calibration and testing services, and data evaluation activities that were carried out during calendar year 1998 in the NIST Physics Laboratory. These activities are 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; frequency; fundamental constants; ionizing radiation; measurement methods; metrology; optical radiation; quantum physics; standard reference materials; time

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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 1998 to December 1998. 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 measurement services and research for electronic, optical, and radiation technology. More specifically, the Physics Laboratory aims to provide 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.

The 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 contribute 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 Divisions.

- **Electron and Optical Physics Division.** Provides the central national basis for the measurement of far ultraviolet and soft x-ray radiation; conducts theoretical and experimental research with electron, laser, ultraviolet, and soft x-ray radiation for measurement applications in fields such as atomic and molecular science, multi-photon 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 standards 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 phenomena and constants; adapts time and frequency standard devices and concepts to special scientific and technological demands; develops time and frequency measurement methods in the 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, it has 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
National Institute of Standards
and Technology,
100 Bureau Drive, Stop 8400
Gaithersburg, Maryland 20899-8400. ▫

FUNDAMENTAL CONSTANTS DATA CENTER

MISSION

The FCDC mission is to:

- 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 Joint Committee for Guides on Metrology (JCGM) to generate and widely distribute guides on expressing measurement uncertainty, and to have them adopted worldwide.

■ **Information Center and Constants Adjustment.** 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 no later than mid-1999 and will provide a new set of recommended values of the constants for international use. This effort includes maintaining the Data Center's bibliographic database on the fundamental constants on the Web.

■ **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 and disseminate publications related to the SI to meet the information needs of the increased users of the SI arising from the Federal Government's conversion to the SI.

HIGHLIGHTS

■ **NIST Reference on Constants, Units, and Uncertainty**. This is a fully integrated Web site at http://physics.nist.gov/cuu that provides in-depth information on the fundamental physical constants, the SI, and the expression of uncertainty in measurement.

The information on the fundamental constants includes the most recent CODATA set of self-consistent values of the basic constants and conversion factors of physics and chemistry in a user-friendly, easily searchable, and printable form. The information on the SI features a concise summary of the essential features of the SI, the rules and style conventions for its use, and the correct typeface to use for symbols in scientific publications. The information on the expression of uncertainty in measurement focuses on the essentials of evaluating and expressing the uncertainty associated with measurement results based on the International Organization for Standardization (ISO) *Guide to the Expression of Uncertainty in Measurement* and NIST Technical Note 1297, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results.*

■ **New Interpretation of the SI for the United States**. A new interpretation of the SI for use in the United States was published in the 28 July 1998 issue of the Federal Register

(FR 63 40334-40340). Since the publication of the 1990 interpretation, the international bodies responsible for the SI made some significant changes to it, and it became necessary to set forth a new interpretation. The changes include: 1) the addition of four new SI prefixes to form decimal multiples and submultiples of SI units; 2) the elimination of the class of supplementary units (the radian and steradian) as a separate class in the SI; and 3) changes in the units not part of the SI that can be used with it. The new Federal Register notice is included in the NIST Reference on Constants, Units, and Uncertainty.

■ **Precision Measurement Grants**. The FCDC awarded, on behalf of NIST, new Precision Measurement Grants to Prof. D.E. Pritchard of MIT and Prof. S.T. Staggs of Princeton University. 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 Pritchard's project, "Accurate Atomic Mass Measurements," is to significantly reduce the uncertainty of the measured values of the relative atomic masses of a number of atoms, especially those required for the improved determination of the fine-structure constant, the Avogadro constant, the critical testing of Einstein's energy-mass relation $E = mc^2$, placing limits on the mass of the electron neutrino, and providing improved values of the relative atomic masses of the proton, neutron, and deuteron.

The aim of Staggs' project, "Measurement of the Polarization of the Cosmic Microwave Background," is to develop a correlation microwave receiver of bandwidth 16 GHz operating at 90 GHz with front-end amplifiers cooled to 15 K and with noise temperatures of less than 50 K, and to use it to make the first observations of the expected 5 μK linear polarization (0.2° diameter sky patch) of the cosmic microwave background (CMB).

FUTURE OPPORTUNITIES

During the next year, we will focus on: revising and publishing new editions of NIST Special Publications 330 and 811 on the SI; and serving as a principal member of the CODATA Task Group on Fundamental Constants, carrying out the work necessary for completing the new 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

The mission of the ECSED office is to:

- coordinate and facilitate the dissemination of Physics Laboratory-generated scientific and engineering data by means of the Internet;
- develop methods and serve as a model for the effective dissemination of scientific and engineering information by means of computer networks;

CURRENT DIRECTIONS

■ **Dissemination of Physics Laboratory Information over the Internet.** The ECSED office is responsible for the Physics Laboratory (PL) world wide web (WWW) pages. It produces 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 the Internet. 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 and the NIST Standard Reference Data Program in developing physical reference databases for dissemination over the web. It designs and develops effective interfaces between the information and the user to facilitate use of the data.

HIGHLIGHTS

■ **Physics Laboratory Information on the WWW.** We began providing information to the public in June 1994. By the end of fiscal year 1998, we were supplying 270,000 PL documents each month to users outside of NIST (fully half from our databases). The rate of use continues to increase rapidly.

A wide array of information is provided by PL on the WWW. It ranges from staff and organization information to PL technical activities, publication lists, research facilities, news items, 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.

For internet users who want to access the PL WWW server, the Internet URL for the PL web server is http://physics.nist.gov/.

■ **Photon Cross Section Databases Developed for PL Web Server.** The ECSED office developed a web version of NIST Standard Reference Database 8, XCOM: NIST X-Ray and Gamma-Ray Attenuation Coefficients and Cross Sections Database by M.J. Berger and J.H. Hubbell. It provides information on the scattering and absorption of photons (x-rays, gamma rays, and bremsstrahlung) which is required for many scientific, engineering and medical applications. In addition to elements, results may be obtained for arbitrary user specified-compounds and mixtures.

■ **Databases of Stopping Powers and Range Tables Developed for the WWW.** The ECSED office developed web versions of the NIST ESTAR, PSTAR, and ASTAR databases of the stopping power and range tables of electrons, protons, and alpha particles, respectively, which were originally calculated by M.J. Berger. They provide stopping power and range information in a large number of elements and materials of interest to the medical, space science, and engineering communities.

■ **Database of Ground Levels and Ionization Energies for the Neutral Atoms Developed for the WWW.** A database consisting of a critical compilation of the ionization energies and ground state configurations by W.C. Martin and A. Musgrove has been made available on the WWW. The data for the first 104 elements is presented as a table and comes complete with bibliographic references. The database provides this important information in an easy to access form.

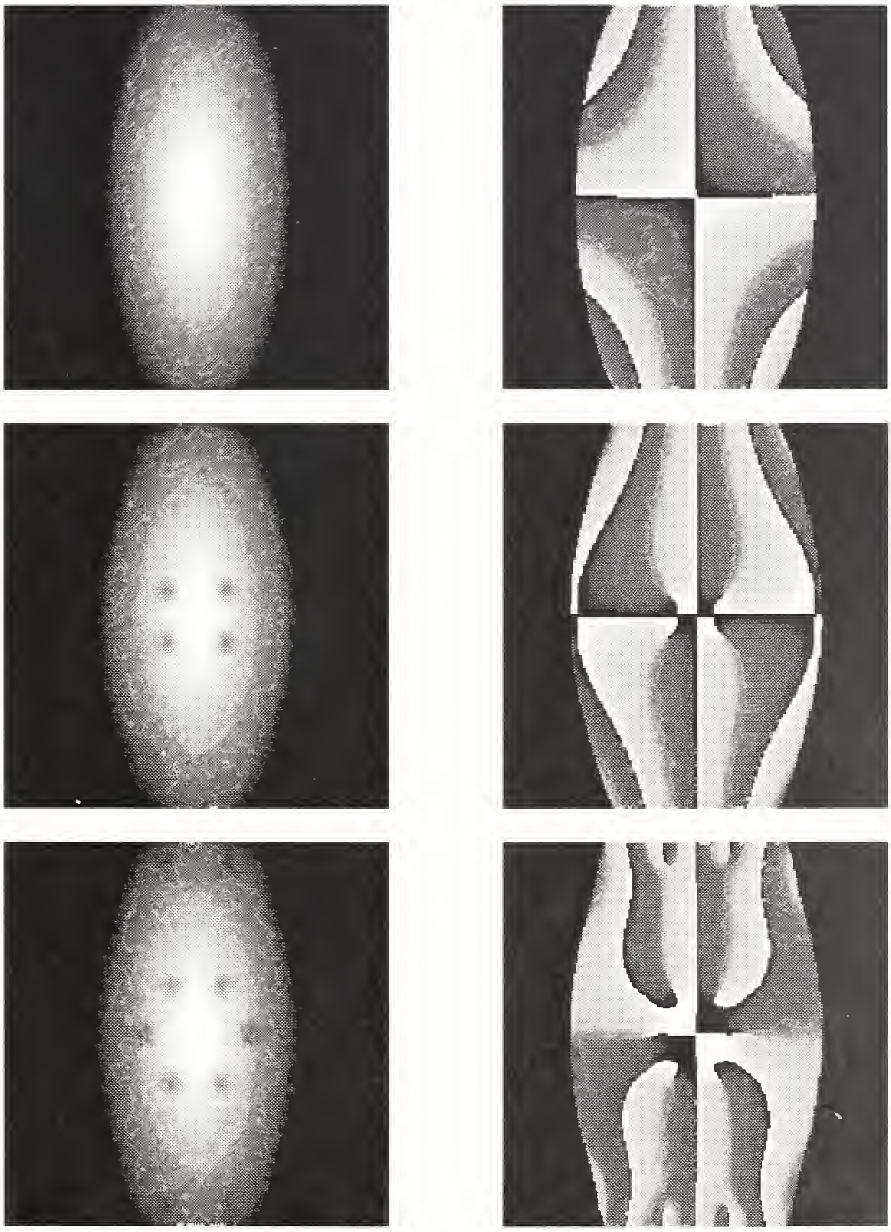
■ **Wide Range of Databases Developed for WWW Dissemination.** This Office develops and makes available over the web a wide range of physical reference databases. In addition to the three mentioned above we provide databases of the Fundamental Physical Constants; Atomic Spectroscopic Information; Spectrum of a Platinum Lamp; Wavenumber Tables for Calibration of Infrared Spectrometers; Frequencies for Interstellar Molecular Microwave Transitions; X-Ray Attenuation and Absorption for Materials of Dosimetric Interest; X-ray Form Factor, Attenuation, and Scattering; Cross Sections for Electron Impact Ionization; Radionuclide Half-Life Measurements Made at NIST; and Bibliographies of Atomic Transition Probabilities, Photon Attenuation Measurements, and Fundamental Constant Determinations.

■ **The NIST Reference on Constants, Units and Uncertainty Available on the Web.** The ECSED Office in collaboration with the Fundamental Constants Data Center made extensive supporting documentation on constants, units and uncertainty available on the WWW. This carefully designed material provides essential support to the many users of the Fundamental Constants Database as well as to the users of the rest of our WWW Physical Reference Data.

FUTURE OPPORTUNITIES

New information is expected to include a totally new database of atomic spectral lines, levels and transition probabilities with many more spectra, a line shifts and broadening bibliographic database, a web version of the compilation of atomic transition probabilities of carbon, nitrogen and oxygen, and a tabulation of the properties of amorphous metals. □

ELECTRON AND OPTICAL PHYSICS DIVISION



Overleaf

Vortex structures in a rotating Bose-Einstein condensate. These vortex structures were obtained by solving the time-dependent Gross-Pitaevski equation for a system of 10^5 atoms of ^{87}Rb in a deformed TOP trap. The condensate density (left) and phase (right) in the plane of rotation are shown for rotational frequencies of 0.5, 0.52, and 0.55 times the frequency of the tight axis (respectively upper, center, and lower frames). The upper frames show irrotational flow of the condensate; in the middle and lower figures, vortices penetrate the condensate and form vortex arrays.

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 eV to 250 eV. This basis is maintained through a combination of ionization chambers, calibrated transfer standard detectors, and an electron storage ring, the SURF II Synchrotron Ultraviolet Radiation Facility, which provides a dedicated source of radiation over this spectral range. SURF II also supports a range of research activities by members of the Division, 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 nm 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.

CURRENT DIRECTIONS

The mission of the Electron and Optical Physics Division is to "apply its core physics competence to solve the measurement problems encountered by electronic, magnetic, and optical technologies at the atomic level." By developing innovative instrumentation and techniques, it maintains world-class capabilities for: determining magnetic microstructure; establishing the physical and chemical basis of device fabrication on the atomic scale; producing and characterizing artifacts with atomic-scale quality control; developing physical and applied optics in the 10 nm to 100 nm wavelength range; maintaining the National radiometric standard in the 2 nm to 250 nm wavelength range; and delivering quality measurement, calibration, and secondary standards services in the 2 nm to 250 nm wavelength range.

In carrying out this mission, the Electron and Optical Physics Division operates major research facilities, performs measurement and calibration services, and pursues basic research.

■ **Facilities Operation**. The Synchrotron Ultraviolet Radiation Facility (SURF III) supports the measurement services and research efforts of the Division, and those of other NIST organizational units and external customers. As discussed below, a major upgrade of the SURF facility has been underway during all of 1998. The key design goal of improving magnetic field uniformity has been attained, and we hope to resume operations early in 1999.

■ **Measurement and Calibration Services**. The Division's activities in calibration and measurement services are centered around SURF II. These activities have thus been performed at a reduced level in 1998 due to the facility upgrade. For the past several years, we have maintained a dedicated reflectometer system on 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 previous years, up to 200 calibrations/year have been performed at this facility, and as interest in EUV optics continues to grow, we expect a rapid return to the previous level of activity. Our spectrometer calibration service on BL-2, carried out primarily in support of NASA programs in solar physics and XUV astronomy, has been suspended during 1998. Our UV and EUV detector transfer standards program usually uses a dedicated beamline (BL-9) and a dual-grating monochromator mounted on BL-2 during calibration. This program performed about 20 calibrations during 1998, using conventional sources.

■ **Basic Research**. The Division's basic research programs have been very productive during the past year. We obtained the first three-dimensional images of integrated-circuit interconnects using x-ray tomography. A new method of patterning silicon was demonstrated: exposure of hydrogen-passivated silicon to a beam of metastable rare gas atoms. Improved understanding of the mechanism of exchange coupling in magnetic thin films was obtained by new measurements and developments in theoretical models. New computational methods were developed to treat degenerate quantum gases, and applied to coherent matter-wave optics. A novel model of magnetization in ultrathin magnetic films on vicinal surfaces was developed. Significant progress was made in the construction of the new nanoscale physics facility.

TECHNICAL HIGHLIGHTS

■ **X-Ray Microtomography of Integrated Circuits.** Three-dimensional imaging of buried structures with sub-micron resolution represents an important tool for analyzing modern engineered structures such as those found in microelectronics, quantum wells, and multilayer magnetic devices. We have begun a program to perform x-ray microtomography of buried structures in integrated circuits, in collaboration with the Intel Corporation, Rensselaer Polytechnic Institute, and Argonne National Laboratory. We have used a 200 nm x-ray microprobe at 1.7 keV photon energy at Argonne's Advanced Photon Source to produce a series of two-dimensional microradiographs with different views of a pair of microelectronic interconnects. Tomographic algorithms were then applied to these microradiographs to synthesize a three-dimensional image of the buried circuit. With a capability of resolving features as small as 400 nm, this work represents the highest resolution tomography ever achieved at a photon energy above 1 keV (A. Kalukin, Z.H. Levine, and T.B. Lucatorto)

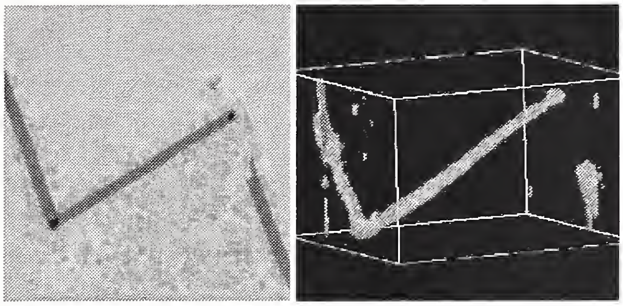


Figure 1. X-ray images of an electromigration sample. This circuit was exposed to high current density, resulting in electromigration damage, which is seen as a break in the line pattern in the frame on the left. The left frame is one of the two-dimensional micrographs that have been tomographically analyzed to generate the three-dimensional image shown in the right frame. The spatial frame width is 10 microns, and the image resolution is 60 nm. The three-dimensional image incorporates data from twelve two-dimensional views, and has a voxel resolution of 180 nm

■ **Improved Radiometric Scale Between 125 nm to 400 nm.** In collaboration with Division 844, we have established a new radiometric facility at SURF for the calibration of photodetectors in the 50 nm to 400 nm wavelength range. The several methods of calibration formerly used in this wavelength range are to be replaced with procedures based on the Absolute Cyrogenic Radiometer (ACR). Initial work in the region from 125 nm to 400 nm, performed before the SURF decommissioning last year, shows that we are able to reduce the maximum uncertainty in this range from 10% to 2%. Our plans are to extend the ACR method down to 116 nm as soon as SURF III is operational, and then to use the method to improve the accuracy in selected intervals in the region from 5 nm to 116 nm. For example, the EUVL-LLC consortium spearheaded by Intel to develop EUV lithography has expressed great interest in improved accuracy in the interval 11 nm to 13 nm. UV and EUV detectors are particularly susceptible to damage and contamination. A program to develop new detector materials and configurations that are more resistant to these deleterious effects is also underway so that the accuracy of the improved scale can be more reliably transferred to the point of application. (U. Arp, L.R. Canfield, T.B. Lucatorto, C.S. Tarrio, and R.E. Vest)

■ **Far UV Transfer Standard Detectors Activity.** During the upgrade of SURF, several improvements were made to the BL-9 detector radiometry system, addressing all of the known marginal hardware sub-systems identified. This system is used to perform absolute calibrations of NIST working standards and relative calibrations of transfer standards in the 5 nm to 50 nm spectral region. Laboratory investigations of possible alternate detector materials in the 50 nm to 254 nm spectral region have continued, with a new photodiode based on platinum silicide/ silicon emerging as a leading candidate. Prototypes of these detectors have shown radiation hardness far beyond the best silicon photodiodes, and may be useful for direct monitoring of the vacuum ultraviolet excimer lasers now being used for medical applications and for lithography. An SBIR Phase I contract was awarded to a manufacturer specializing in the production of far ultraviolet photodiodes, and the early progress has been excellent. For the first time, silicon avalanche photodiodes have been investigated in the far ultraviolet. Design modifications indicated by these studies were conveyed to the manufacturer, and improved structures will be tested when they become available. An absolute trap detector for the region just longer than 160 nm was designed, constructed, and tested. The results confirm that absolute measurements of incident radiation can be made without the need for device calibrations. Twenty calibrations of transfer standard calibration detectors were performed during 1998 for applications in solar physics, astronomy, aeronomy, and plasma diagnostics. (L.R. Canfield and R.E. Vest)

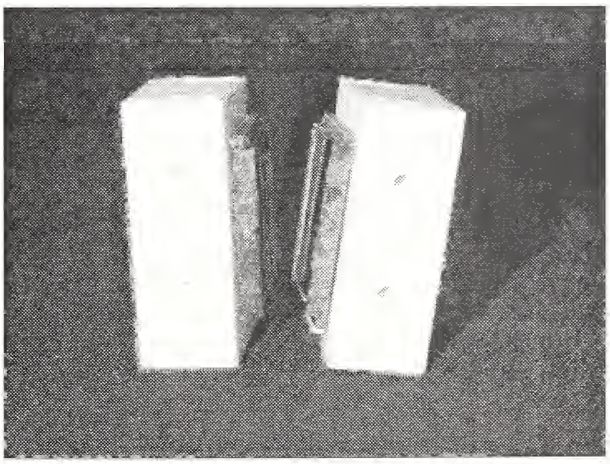


Figure 2. Prototype of new trap detector for use as transfer standard from 160 nm to 200 nm.

■ **SURF III Upgrade.** The SURF accelerator upgrade project, begun in September 1997, is nearing completion. The principle objectives of this project are to improve the accuracy of the SURF electron storage ring as a primary standard source of spectral irradiance, and to extend the spectral range. These goals were to be achieved through complete replacement of the electromagnet components and control systems.

The main components of the SURF electromagnet are the upper and lower yokes, the two backlegs, the upper and lower poles, the upper and lower main coils, and the correction or trim coils. All the steel magnetic components for the SURF II electron storage ring were of laminated construction to prevent large eddy current production. Lamination was necessary since the steel was originally designed for the SURF I synchrotron, which operated at 60 Hz. The SURF III steel is constructed of solid blocks, permitting a larger on-orbit field in its slightly larger footprint.

The new magnet material was delivered to NIST in December 1997, and construction began immediately. Each yoke consists of five blocks, each weighing approximately 15 tons, which were carefully aligned to each other within the exacting tolerance of ±25 µm (0.001 in). The assembled lower yoke section, weighing approximately 75 tons was centered to the same location as the SURF II lower yoke to within ±250 µm. Construction of the magnet was completed in May 1998, and a magnet mapping system was installed at that time.

The careful construction of the electromagnet and a new design for the magnetic poles was intended to create a highly circular orbit for stored electrons and the capability to accurately measure the characteristics of the magnetic field produced. The critical measurement for orbital circularity is azimuthal uniformity of the magnetic field. Horizontal and vertical fiducial surfaces were accurately machined near the outer perimeter of the upper and lower pole pieces. An air bearing rotary table was centered on the lower yoke and made parallel to the lower yoke's upper surface. A rod with a dial indicator attached was bolted to the rotary table and used to position the upper and lower poles to the same center as the lower yoke center. Final measurements showed that the pole centers and lower yoke center were all aligned to within ±10 µm (0.0004 in).

Another critical parameter for operation of SURF III is the radial magnetic field gradient. The poles were designed with a particular shape to produce the gradient for optimum performance. In order to achieve the design gradient it is critical for the magnetic poles to be parallel. Measurements of the gap between the horizontal fiducial surfaces were made with an inside micrometer to determine parallelism. Analysis of these measurements reveals that the pole faces are parallel to within 3 µrad. The rotary table was removed and replaced by a magnet mapping system consisting of two probes that could be moved both radially and azimuthally and a stationary probe attached to the upper pole. This system was used to measure the field gradient and to determine the azimuthal uniformity of the magnetic field. The field gradient was well within the design parameters. The magnetic field in the range corresponding to electron energies from 105 MeV to 405 MeV is azimuthally uniform to better than 2 parts in 104. A sample azimuthal field measurement is shown in Fig. 3 for an electron energy of 388 MeV. For comparison, the dotted line shows the field for SURF II at its highest energy, 302 MeV)

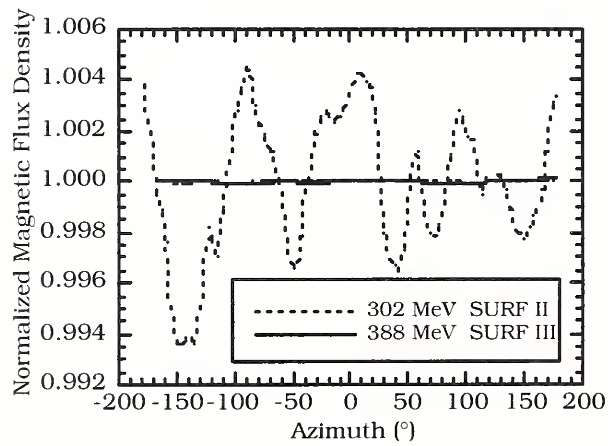


Figure 3. Comparison of the azimuthal field uniformity of SURF II at the maximum energy of 302 MeV with the uniformity of SURF III at 388 MeV.

During the construction of the SURF III magnet, several modifications were made to the storage ring vacuum chamber: new instrumentation for beam diagnostics and ion neutralization were installed; two new beamports were added; and two existing beamports were modified to increase their angular acceptance, optimizing the beamlines for use in the infrared spectral region. On October 21, 1998 the vacuum chamber was installed and the magnet top was set in place for the final time. The control system has been updated and is ready to run SURF III in the standard operational mode. Testing of the rf system at the increased power levels necessary to store electrons at energies greater than 300 MeV is complete. Initially, the maximum electron energy will be limited to 350 MeV due to the characteristics of the accelerating cavity. Even at this energy, the photon flux in the "water window" from 2.3 nm to 4.4 nm is increased by an order of magnitude over the flux available from SURF II. As of November 1998, assembly of the injector vacuum system is nearly complete, and the commissioning process is expected to begin in late November 1998. All indications are that SURF III will be operational before the end of 1998. (M.L. Furst, R.M. Graves, A. Hamilton, L.R. Hughey, R.P. Madden, A. Raptakes, and R.E. Vest)

■ Patterning of Silicon by Metastable Atom Impact Depassivation. In a collaboration with researchers at Rice University and Cornell University, we have demonstrated a new way to pattern silicon. Instead of coating a wafer with resist and exposing it to radiation (such as photons, electron, or ions), the new technique uses hydrogen-passivated silicon and exposes it to a beam of metastable rare gas atoms. Hydrogen-passivated silicon consists of an ordinary silicon surface on which the dangling bonds have been terminated with hydrogen atoms. With this termination the silicon surface is extremely passive and will not form an oxide. When a metastable atom strikes the surface, however, its internal energy is released and a hydrogen atom is ejected. This depassivation allows oxide to form (provided oxygen is available), which can then serve as an etch resist. Patterning of the surface is achieved by imposing a pattern on the incoming metastable atom flux—either by using a mask, as was done in the first demonstrations of the process, or by manipulating the metastable atoms with laser light. The latter approach holds promise for pushing the resolution of this patterning technique well into the sub-100 nm regime, as has been demonstrated in related work on laser-focused atomic deposition of Cr atoms. Because the "grain size" of the hydrogen passivation is a single hydrogen atom, the ultimate resolution limit of this new technique is likely to be on the atomic scale. (J.J. McClelland and R.J. Celotta)

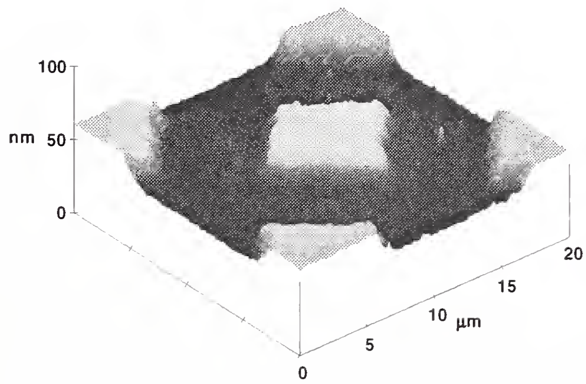


Figure 4. Atomic force microscope image of a silicon surface patterned by metastable atom impact depassivation. A beam of $Ar(^3P_{0,2})$ atoms passes through a square mesh and strikes the hydrogen-passivated surface. The surface is exposed to oxygen and then etched in KOH. In the regions struck by metastable atoms, the passivation is removed, allowing oxide to form. The oxide resists etching, so the pattern is transferred into the surface.

■ Magnetic Exchange Coupling Strengths of Antiferromagnets. As part of a continuing program to understand the physical basis of magnetic coupling in magnetic multilayers, we measured the exchange coupling between Fe films separated by Ag, Au, Cr, Mn, V, Cu, or Al spacer layers. The films were grown epitaxially on nearly perfect Fe whisker substrates in order to achieve the atomic scale precision necessary to make meaningful comparisons with theory. The coupling through antiferromagnetic spacers, Cr and Mn, is especially of interest because of the current use of antiferromagnets to exchange bias spin valve structures. Figure 5 shows a measurement of the Fe/Cr/Fe exchange coupling strength. The sample for this measurement consists of a variable thickness Cr wedge deposited on the Fe whisker and topped with a thin Fe film. The figure consists of a series of magneto-optic Kerr images taken at different applied magnetic fields. The dark bands correspond to Cr thicknesses at which the Fe film is antiferromagnetically coupled to the whisker. When the applied magnetic field exceeds the exchange coupling strength, the Fe film magnetization becomes aligned with that of the whisker. The composite image therefore graphically shows the thickness dependence of the antiferromagnetic exchange coupling strength. Although Cr coupling strengths have been measured before, this is the first time that an Fe/Cr/Fe multilayer has been grown with sufficient precision to clearly see the spin density nature of the Cr in the coupling strength measurement. Cr is not an ideal ferromagnetic with a 2 layer periodicity, but an incommensurate spin density wave antiferromagnet with a 2.05 layer periodicity that leads to the modulated envelope of the coupling strength in Fig. 5 and the node at about 24 layers. This figure also shows how difficult measuring coupling strengths of well-ordered Fe/Cr/Fe structures one thickness at a time can be: a change in the Cr thickness of only a tenth of a monolayer can lead to over an order of magnitude change in the exchange coupling strength.

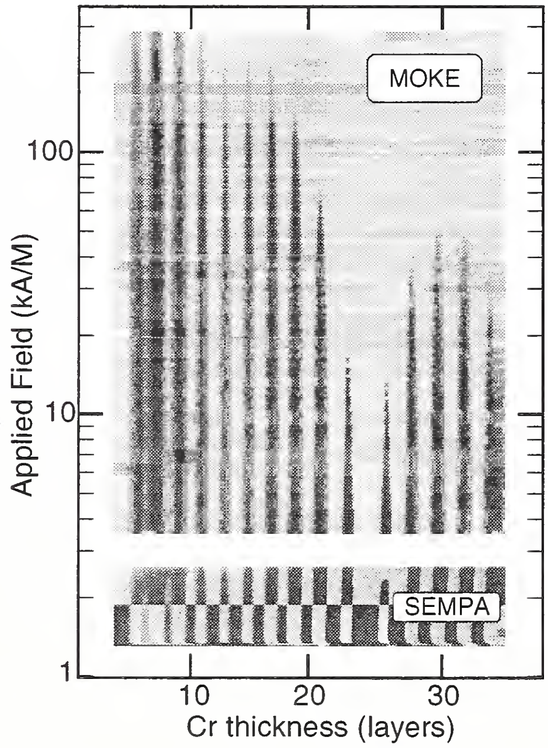


Figure 5. A series of MOKE images from an Au(10 ML)/Fe(15 ML)/Cr wedge/Fe whisker sample taken at various applied magnetic fields, showing the field and Cr thickness dependence of the reversal of the antiferromagnetic regions (dark bands). The Fe/Cr/Fe exchange coupling strength is determined from the switching field. A SEMPA image of the same wedge at zero applied field is shown at the bottom for reference.

We were also able to measure the temperature dependence of the Fe/Cr/Fe coupling in our nearly ideal Cr wedge structure. Figure 6 shows SEMPA measurements as a function of temperature. This data clearly shows oscillatory coupling well above the Neel temperature of bulk Cr, T_N=311 K. The coupling periods and hence the nodes in the exchange coupling are very sensitive to temperature. Figure 6 also includes curves showing the thickness at which the phase slips in bare Cr/Fe occur. Like the Cr/Fe case, the short period oscillations in Fe/Cr/Fe exist to nearly twice the bulk T_N and the phase slips have nearly the same temperature dependence. Locating the phase slip is somewhat difficult in Fe/Cr/Fe because the short period coupling strength appears to drop off more rapidly with temperature than that of the long period. The temperature dependence of the coupling also leads to reversals in the direction of the coupling, i.e., below 420 K the coupling at 30 layers is antiferromagnetic, while above 500 K the coupling switches to ferromagnetic. Our measurements are qualitatively similar to neutron scattering measurements which find a commensurate spin density wave below and incommensurate spin density wave above the first phase slip. However, the boundary dividing the two regions of spin density wave behavior saturates at about 300 K in the neutron measurements but extends to well over 500 K for our samples. (J. Unguris, R.J Celotta, D.T. Pierce, and D. Tulchinsky)

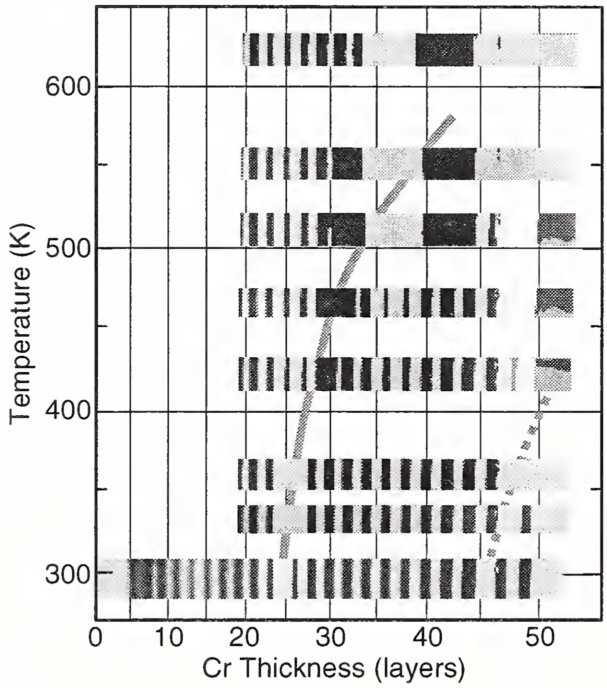


Figure 6. The temperature dependence of the bilinear exchange coupling in Fe/Cr/Fe. The phase slips measured on bare Cr are shown by the solid gray line; the dashed line is the estimated position of the next phase slip. Note that the short period oscillations, where visible, have opposite direction at temperatures below and above these lines.

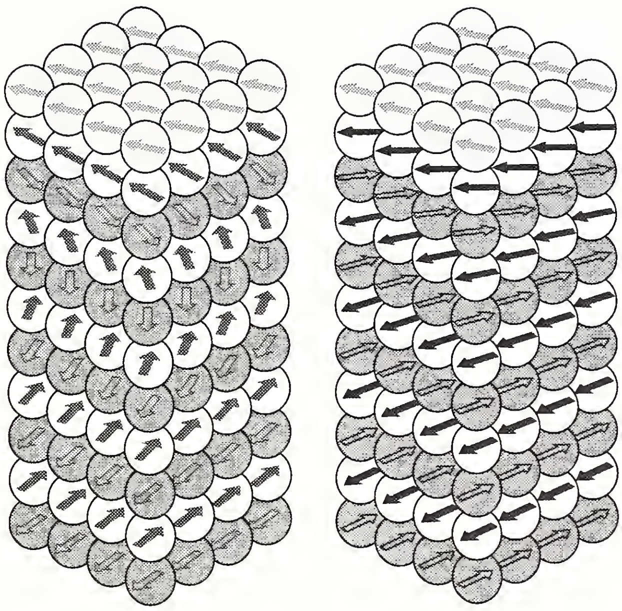


Figure 7. Partial domain walls, which are wound up by coupling to a ferromagnetic thin film, in a model antiferromagnetic grain.

■ **Model for Exchange Bias.** We have developed a model for exchange bias, an effect that arises from the coupling between a ferromagnetic thin film and an antiferromagnetic film. Exchange bias is the shift in the hysteresis loop of the ferromagnetic thin film due to this coupling. While this effect has been known for a long time, there has been a great deal of recent interest because the shift in the hysteresis loop is useful for pinning chosen ferromagnetic thin films in thin film devices. In particular, devices called spin valves, which incorporate such films, are used in the most recent read heads for magnetic disk storage. In these devices, the magnetization of a free magnetic layer rotates in response to applied fields while the magnetization of another magnetic layer is pinned by exchange bias. The changing relative magnetization of the two layers gives rise to a changing resistance through the giant magnetoresistance effect. The interaction between the ferromagnetic and the antiferromagnetic films is poorly understood. Many experiments carried out to understand these systems indicate that there are irreversible effects occurring in the antiferromagnetic layers. We have developed a model for the coupled system that explains both the exchange bias and the irreversible processes. The model is based on winding partial domain walls in the antiferromagnet as the ferromagnetic magnetization is rotated. In some grains, these partial domain walls are stable; these grains give rise to the exchange bias. In other grains, the partial domain walls become unstable at some critical thickness and give rise to the irreversible effects. (M.D. Stiles).

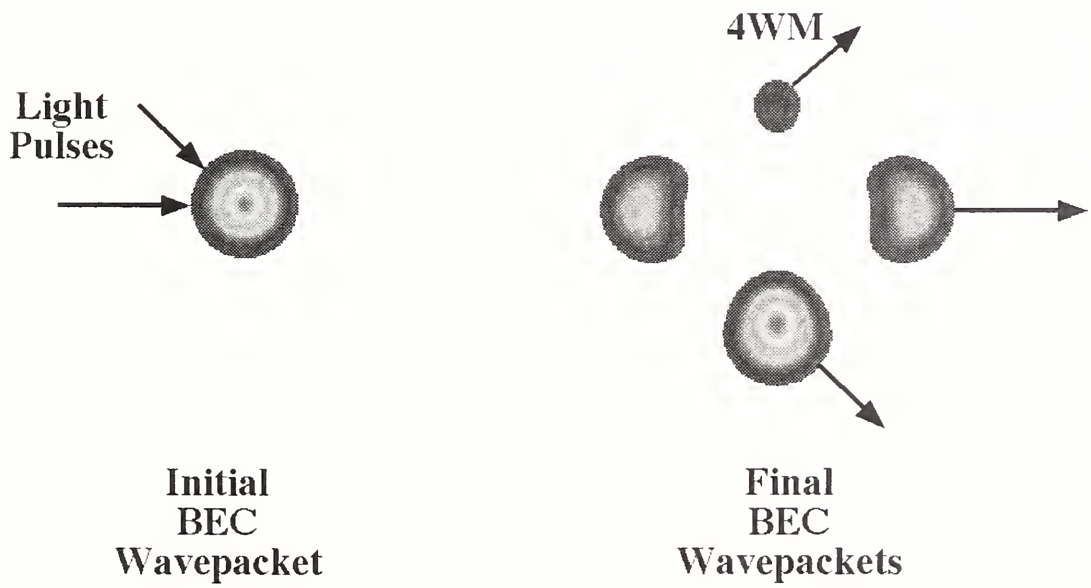
Future Directions

■ **High Resolution SEMPA.** Continually increasing magnetic storage densities and new magnetic technologies such as spintronics require higher resolution imaging of magnetic microstructure than is currently available. In order to respond to industry's needs for higher resolution magnetic imaging tools, we are upgrading our SEMPA facilities. We will take advantage of recent advances in commercial SEM design that have significantly improved spatial resolution, and combine our best, NIST built, electron spin polarization analyzers with a new state-of-the-art SEM. The resulting SEMPA instrument will replace our two aging SEMPAs and provide us with the following improvements: the resolution will be improved by a factor of 2 to 4 allowing sub-10 nm magnetic imaging. The spin analyzer sensitivity will be increased by a factor of 10 to 30 over our current high resolution SEMPA. And, finally, the improved reliability of a new instrument will reduce operating costs and avoid frustrating our industrial customers. The new SEMPA instrument will also have the capability of applying local magnetic fields, so that the relationships between the magnetic microstructure and various relevant magnetic properties such as magnetoresistance can be studied as a function of the applied magnetic field.

■ **Quantum Electronics and Autonomous Atom Assembly.** The Electron Physics Group is undertaking a new program to develop the measurement capability that will allow researchers to probe the underlying physics in quantum confined structures on the nanometer length scale. Electron systems confined to nanoscale dimensions develop quantized energy levels on which a new branch of electronics, quantum electronics, may be based. To meet the measurement challenges that must be overcome to be able to study and understand the quantized energy level structure on a nanometer length scale, the Electron Physics Group is building the Nanoscale Physics Facility. This unique facility combines MBE fabrication methods, to create nanostructures, with a cryogenic scanning tunneling microscope to measure the electron energy level structure. The microscope is of a versatile design for fast turnaround of samples. It will operate at temperatures down to 2 K in intense magnetic fields of up to 10 tesla. To fabricate nanostructures, the facility will employ traditional methods of MBE growth of metal and semiconductor structures in separate vacuum systems with *in situ* transfer of samples to the microscope. In addition, a novel nanofabrication system is being developed to perform autonomous atom assembly of nanostructures, i.e., the atom-by-atom assembly of desired, complex nanostructures under completely autonomous computer control. □

ATOMIC PHYSICS DIVISION

Four-wave Mixing of Matter Waves



Overleaf

Four-wave Mixing of Matter Waves. This figure shows the predictions of a numerical simulation of four-wave mixing of matter waves derived from a Bose-Einstein condensate (BEC) of sodium atoms. This is an example of nonlinear atom optics. The process is analogous to four-wave mixing in ordinary nonlinear optics, by which three light waves are mixed to generate a new light wave. The left side of the figure shows an initial BEC wavepacket. Two light pulses use Bragg scattering to produce BEC traveling waves with recoil momenta directed as indicated. After the light pulses, there are wavepackets with three momenta present: the initial BEC with zero momentum, and the two new wavepackets moving in the directions indicated. Nonlinear mixing among the three matter-wavepackets produces a new matter-wavepacket not initially present with a fourth momentum. Energy and momentum are conserved in this process. The three fast moving matter-wavepackets separate after a short time. This is indicated on the right side of the figure, which shows the four wavepackets, including the new one produced by four-wave mixing. The simulations were carried out by integrating the time-dependent nonlinear Schrödinger equation which characterizes a zero temperature BEC. The predictions of the theory have been verified by a recent experiment by the NIST Laser Cooling Group.

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, and it explores atomic interactions in plasmas and with surfaces;
- provides measurements, standards, and data support for specific needs in various industrial and scientific applications such as the processing of materials by plasmas and ion beams, commercial and residential lighting, optical materials characterization, spectrochemistry, x-ray analysis of thin films, and fusion plasma diagnostics;
- contributes to advances in fundamental standards by atomic fountain clock research, by studies of the Si-lattice for the unit of mass and by refining the electromagnetic scale through the linking of standards in the visible to others in the x-ray and gamma-ray regions;
- 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 optical manipulation of neutral atoms using Bose condensates and optical lattices; 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.

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 about 30 professional staff members, 7 postdocs, and about 30 longer-term (>3 months) guest scientists and contractors.

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 (≈1 %) for light atoms (atomic numbers $Z < 20$) so that these theoretical results may serve as benchmarks for experiments and other theories.

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

On the experimental side, with our computer-automated electron beam ion trap (EBIT) we can now directly measure lifetimes of highly charged ions. A 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 ultra-high resolution Fourier Transform Spectrometer has a greatly improved data acquisition system, and we are recording and analyzing complex spectra of selected heavy elements. We are also measuring numerous transition probabilities for lines of neutral and singly ionized atoms.

■ **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 critical evaluations and compilations of wavelengths (including an all-Z tabulation of x-ray wavelengths), atomic energy levels, and transition probabilities. The data assessment greatly benefits from our own atomic data research discussed above. We have put a large part of our comprehensive data tabulations on the World Wide Web and will update and expand this coverage.

■ **Properties of Nanoscale Systems**. Our expertise in atomic systems is being extended to include properties of nanoscale systems. One direction is to 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. Another direction is the modeling of images produced by scanning near field optical microscopy, which offers the prospect for nanometer-scale optical metrology.

■ **Physics of Cold, Trapped Gases of Neutral Atoms.** We are investigating, both experimentally and theoretically, the properties of cold dense gases in the quantum degenerate regime. We are using atom optics techniques to study the properties of Bose-Einstein condensates, and are developing such devices as an atom laser. The interactions between atoms strongly influence the properties of the condensate. The effects of such interactions are being theoretically modeled and tested against the experimental data. The nonlinear Schrödinger equation is used to predict properties of matter waves produced from a condensate.

■ **Ion-Surface Interactions.** With a special EBIT ion interaction beamline we are investigating the atomic scale interaction of very highly charged ions ($Q \gg 30+$) with surfaces. The work makes use of a new ultra-high vacuum, *in-situ* scanning tunneling/atomic force microscope and a sample preparation chamber on the EBIT beamline. We are also using a new detector to observe particle induced X-ray emission from silicon surfaces bombarded with highly charged ions from EBIT. Also, we have demonstrated an approach to projection lithography using ions with extremely high charge states and are now studying this technique in detail.

■ **Plasma Measurements.** The Division uses nonintrusive optical emission measurement techniques to determine the properties of radio frequency (rf) inductively coupled and arc discharge 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.

■ **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 new kinds of physics measurements in areas such as high-resolution spectroscopy, atomic collisions, and atom optics aiming, for example, at improving atomic clocks.

■ **Optical Manipulation of Biological Objects.** We are developing techniques for the remote manipulation of biological objects. We use laser trapping to manipulate cells, chromosomes and microspheres in order to study bio-molecular interactions. Applications of these investigations include fundamental studies of adhesion processes in biological systems, development of highly effective inhibitors of adhesion, and very sensitive biosensors.

■ **Precision Crystal, X-ray, and Gamma-ray Measurements.** This work has three components: Optically-based measurements of a silicon lattice period (XROI), inter-crystal comparisons (delta-d), and Bragg-Laue diffraction studies using two-crystal instruments here and at the high flux reactor in Grenoble, France. XROI measurements are part of the new sub-atomic displacement measurement project. Delta-d measurements are used to determine the lattice spacings of crystal samples used for x- and γ-ray diffraction, and to compare crystal samples from the standards laboratories that are making absolute lattice spacing measurements [Germany, Italy, Japan]. They also are used to characterize the starting material for the Avogadro project and the next generation of Si powder diffraction Standard Reference Materials (SRM's). The joint NIST-ILL GAMS4 precision double crystal spectrometer at the Institut Laue-Langevin (ILL) measures γ-rays leading to new, accurate determinations of the neutron mass, the molar Planck constant, N_Ah, and atomic mass differences. At Gaithersburg, measurements to complement the x-ray wavelength tables project are made, using a second two-crystal transmission spectrometer (high-Z region) and a vacuum spectrometer (energy region below 15 keV).

■ **High-Resolution X-Ray Probes of Geometrical and Electronic Structures.** We have developed a high resolution x-ray toolset for the study of the electronic and geometrical structure of materials ranging from the most perfect silicon monocrystals through epitaxial layers, thin films and multilayer structures, to surfaces and sub-surface damage in technical artifacts. Electronic structure questions are addressed by diverse spectroscopic techniques while the geometrical aspects are probed by several diffraction methods. Both areas are supported by a high performance Dual Ion Beam-Assisted Deposition capability for the production of reference quality layer and multi-layer structures. In current applications of this work to semiconductor and magnetic storage technology, the goal is to delineate the structure in order to understand the effect of this meso-organization on materials and device performance. In the limit of highly perfect monocrystals, our interest is in the metrology of the remaining imperfection.

■ **Sub-atomic Displacement Metrology.** Linear displacement is a primitive component of many fundamental physical and technical measurements, yet its realization with atomic scale refinement and accuracy is difficult. Optical interferometry is the means by which a displacement is related to a primary wavelength standard, and at the moment the accuracy of an interferometric measurement is at least two orders of magnitude below that of the reference laser. We have a competence project (in collaboration with MEL) aimed at improving understanding and application of interferometry. The one-dimensional displacement of a specially fabricated translation stage will be simultaneously measured by means of heterodyne Michelson interferometry, scanning Fabry-Perot interferometry, and x-ray interferometry. The redundancy inherent in this approach will allow robust control of the systematic errors that currently limit the accuracy of displacement measurements. We are currently working towards measuring a displacement of up to 5 cm with 50 pm resolution in a high-vacuum, vibration controlled environment.

HIGHLIGHTS

■ **High Resolution FTS Upgrade Completed.** Operating characteristics of our high resolution Fourier transform spectrometer (FTS) have been greatly improved by replacement of a number of electronic and mechanical components. Our new data acquisition system has been completely redesigned, tested, and installed on the spectrometer. This completes the modernization of all components of the electronic systems of the instrument. We have also replaced the linear motors and motion control system, giving us a simpler and more easily maintained system that eliminates one of the auxiliary interferometers with no reduction in performance. These instrument upgrades in conjunction with software improvements have produced a significant improvement in signal-to-noise ratios and have reduced ghosts in the system to a negligible level. (G. Nave, U. Griesmann, R. Kling)

■ **Rare Earth FTS Spectroscopy for Lighting Applications.** We have used our high resolution FTS to measure branching ratios for over 300 lines of Dy I and II in the range 400 nm to 2500 nm. This work has been combined with complementary work at the University of Wisconsin for a comprehensive set of branching ratios in these spectra. The results are important for the development of more efficient commercial lighting. Rare earth admixtures in high-pressure lamps are being utilized by the lighting industry both to increase luminosity as well as to achieve better color rendering, and atomic data for rare earth spectra are needed for the modeling of future lamp designs. We have also taken spectra of a Mn hollow cathode lamp in the VIS/IR region. This will be combined with UV data to obtain branching ratios for Mn II lines of interest to space astronomy groups. (G. Nave, R. Kling, U. Griesmann)

■ **High Resolution Spectroscopy for Space Astronomy.** We made new observations of the spectrum of singly-ionized mercury (Hg II) in the visible and near infrared with a pulsed radio-frequency discharge on our 10.7 m air Eagle spectrograph. These observations provide the first accurate wavelengths for Hg II in this region. We have now classified nearly 500 lines as transitions between 90 energy levels. Some of these are transitions in the visible that originate from levels of the $5d^96s5f$ configuration lying well above the ionization limit and that terminate on levels of $5d^96s6d$ lying just below the limit, a most unusual occurrence. From our new level values an accurate value for the ionization energy was determined. All of our results for Hg II are being assembled into a comprehensive report that will contain a complete quantum mechanical interpretation of the Hg II level structure. This report, which will also provide calculated transition probabilities, will constitute the first modern description of the spectrum and energy levels of this important atomic ion.

A portion of our results for Hg II have been incorporated into a collaborative report with several astronomers that analyzes the abundance of mercury in the chemically peculiar stars chi Lupi and HR7775. These stars have an abundance of Hg about 10^5 times the solar abundance. They also exhibit isotopic abundance anomalies. In chi Lupi, for example, the observed Hg is all in the form of isotope 204, the heaviest stable isotope, which comprises only 7% of terrestrial Hg. Many of our results for Hg II as well as for Bi I, II, and III, Hg III, Pb III, Zr II and III, Y III, and Sb II have been used in an atlas of observations of chi Lupi from the Goddard High Resolution Spectrograph prepared by Hubble Space Telescope scientists. (C. Sansonetti, J. Reader)

■ Quantum Electrodynamic Effects in Low Energy Levels of Helium. Accurately determined ionization energies for the low 1*sns* and 1*snp* (*nS* and *nP*) levels of helium furnish excellent tests of calculations for this important three-body system, including two-electron quantum-electrodynamic (QED) effects. By combining a variety of high-accuracy measurements of transitions in helium, we derived ionization energies for several low *nS* and *nP* levels. The uncertainties for the $n = 1$ and $n = 2$ levels vary from 8 parts in 10^9 for the ^1S ground level to 5 parts in 10^{11} for the $2\,^3S$ level. Corresponding theoretical energies including QED shifts of order α^3 atomic units and higher were calculated by Gordon Drake of the University of Windsor, Canada, except for the three lowest levels. For these most accurate levels the main part of the QED shift of order α^3 was based on a preliminary calculation of the Bethe logarithm which was completed in final form by an NRC Postdoctoral Associate at NIST. This particular calculation has been the object of theoretical studies for over 40 years. This latest calculation provides the definitive result, with an improvement in accuracy over previous calculations of about four orders of magnitude for the Bethe logarithm and two orders of magnitude for the energy levels.

Comparisons of the experimental energies with the less accurate calculated values for the seven 1*S*, 2*S*, and 2*P* levels give agreements well within the estimated theoretical uncertainties of 1 to 3 parts in 10^8. The results verify the usefulness of the Kabir-Salpeter formalism for calculating QED shifts at least up to order α^4. Much work is still needed, however, to obtain a two-electron theory of higher-order relativistic and QED contributions approaching the accuracy in hydrogen. (W. Martin and J. Baker)

■ Atomic Interactions and Collisions of Cold, Trapped Atoms. The control of atomic interaction parameters and collision rates by magnetic or optical fields is an important goal of research on cold atoms. Applications include manipulation of the properties of Bose-Einstein condensates, cold molecule formation, and quantum computing. We have started new calculations for the properties of magnetically or optically induced scattering resonance states near zero collision energy. Our calculations quantitatively explain the strength and width of several such resonances recently measured in a sodium Bose-Einstein condensate. We also have set up the time-dependent Gross-Pitiaevskii equation and have predicted nonlinear four-wave mixing of matter wavepackets generated from Bose-Einstein condensates, an effect that has now been observed experimentally at NIST (see also the division's cover picture and the highlight on "nonlinear matter wave optics with Bose-Einstein Condensates" which contains another figure). Calculations of the matter wave coherence agree with experiment and other recent calculations. (C. Williams, P. Julienne, E. Tiesinga, P. Leo, F. Mies, M. Doery, M. Trippenbach, Y. Band)

■ Electron Impact Ionization Cross Sections. The semiconductor industry is shifting toward theoretical modeling of etching by plasma processing to save time and expenses in designing new chips. One critical need for such modeling is the ionization cross section of halogen molecules used in etching. We have developed a Binary-Encounter-Bethe model (BEB) for calculating such cross sections. It is the only *ab initio* theory in the world that can distinguish reliable experimental data from less reliable data for large neutral molecules of interest to the semiconductor industry. The

BEB model has also been found to be effective for atomic and molecular ions of low charge states. A new collaboration with a quantum chemistry group at NIST has been initiated in addition to the existing collaboration with researchers at CalTech and NASA Ames Research Center to predict reliable ionization cross sections for large and complex molecules. New results are being posted on the Physics Laboratory Web site (http://physics.nist.gov/ionxsec) as they are published. Modelers of plasma processing in the semiconductor industry (e.g., Intel, Motorola, Phillips) have started to request theoretical cross sections for molecules of interest to them. (Y.-K. Kim, M. Ali)

■ **Complex Quantum Nanostructures.** Quantum nanostructures are being studied by many labs to realize their promise of enhanced optoelectronic devices. We have implemented realistic, empirical, tight-binding models in our theory of quantum dot structures and used these models to study CdS/HgS and CdTe/ZnTe quantum-dot quantum-wells and Ge nanocrystallites. Our atomistic models allow us to study quantum nanostructures down to the smallest sizes, such as quantum-dot quantum-wells with layers as thin as one monolayer and tightly confined systems with indirect gaps (Ge) or strong valence-band/conduction-band mixing (InAs), where effective mass models are expected to break down. We have also extended our theory of T-shaped quantum wires to include the effects of magnetic fields. This has allowed us to explain recent magneto-photoluminescence experiments on these systems and provides a compelling description of confinement effects in these structures. (G. Bryant and P. Julienne)

■ **Theory of Near-Field Optical Microscopy.** Near-field microscopy offers optical resolution much better than the diffraction limit. Detailed theory and modeling is needed to interpret and analyze near-field images. We developed a coupled dipole theory for imaging with transmission near-field optical microscopy (NSOM) and applied it to accurately model experimental NSOM images of Au nanoparticles. It is critical to model the entire imaging process because it allows us to clearly identify the contribution of the near-field optical excitation source, the coupling to the sample local fields, and the collection optics to NSOM image formation. We find that field enhancement under the metal cladding of the NSOM probe critically determines the structure in the NSOM images. We also modeled the near-field nonlinear optical response of nanoscale structures to understand how near-field optics can be used to extend the capabilities of nonlinear optical spectroscopy. (G. Bryant and P. Julienne)

■ **Comprehensive Spectra Database on the World Wide Web.** The Atomic Spectra Database (ASD) interactive Web server has become accessible at the NIST Physics Laboratory Web site: http://physics.nist.gov/asd. The new version 2.0 of ASD contains significantly more extensive coverage than previous versions. It contains data on about 950 spectra, with about 70,000 energy levels and 90,000 lines from 1 Å to 200 μm, 40,000 of which have transition probabilities with estimated accuracies. Wavelengths of observed transitions are included for the first 99 elements in the periodic table. ASD offers a comprehensive range of user-specified options and selection criteria and includes a "Help" file, which also serves as a users manual. (P. Mohr, D. Kelleher, W. Martin, J. Fuhr, A. Robey, and W. Wiese)

■ **Fundamental Constants – Toward a Better Rydberg constant.** Recently, there has been a dramatic increase in the frequency metrology of hydrogen, and it is expected that the 1*S*-2*S* transition in hydrogen will eventually be measured to 1 Hz, a relative uncertainty below 5×10^{-16}, possibly using trapped hydrogen atoms. In order for the anticipated improvement in experimental precision to provide better values of the fundamental constants, there must be a corresponding improvement in the precision of the theory of the energy levels in hydrogen, particularly in the Lamb shift. As a first step toward this goal, we have carried out a numerical calculation of the one-photon self energy of the 1S state. Numerical convergence acceleration techniques were developed to decrease the substantial computation time by about three orders of magnitude. The result is the first complete calculation of the self energy in hydrogen and provides a value that contributes an uncertainty of about 0.8 Hz. The result is a step toward an improved value of the Rydberg constant and possibly toward the use of hydrogen as a frequency standard over a wide range of frequencies. The calculation was done in collaboration with the Technical University of Dresden, Germany. (P. Mohr and U. Jentschura)

■ **Critical Compilations Uncover Serious Problems for Calculated Transition Probabilities.** The vast majority of transition probability data for atoms and ions are computed. In comparing the sophisticated atomic structure codes (there are about half-a-dozen in existence), we have found that the agreement is usually excellent for the strongest transitions, but that disagreements typically become greater than 50% for oscillator strengths smaller than 0.1 and increase to one or more orders of magnitude with further decreasing strengths. Figure 1 shows an example of the severity of the problem.

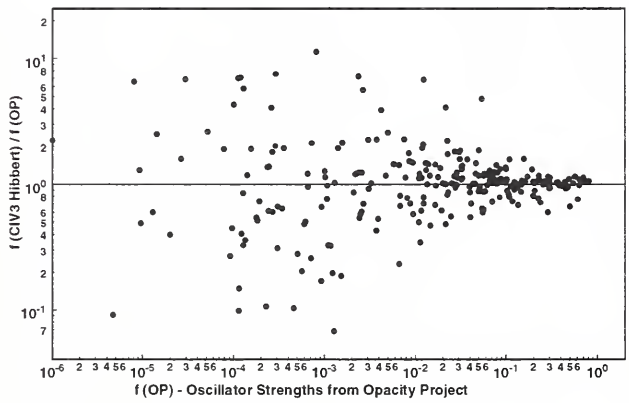


Figure 1. Comparison of two different theoretical data sources for oscillator strengths, showing order of magnitude discrepancies.

We have alerted the data generators to the seriousness and extent of this problem. Also, we organized a special session on this problem at the Sixth International Conference on Atomic Spectra and Oscillator Strengths, August 1998, in Victoria, B.C. This has sparked renewed and more critical work at several institutions focusing on spectra and transitions that we recommend. The first new high-accuracy computations in response to our requests are already producing promising data for noble-gas-like spectra. (D. Kelleher, J. Fuhr, and W. Wiese)

■ **Atomic Spectral Line Broadening Bibliographic Database Issued.** The first bibliographic database on atomic spectral line broadening has been completed and made available on the NIST Physics Lab Website. This database contains approximately 850 recent references for the time period 1993 to 1998, all collected after the last published NIST bibliography: [NIST Special Publications 366, Supplement 4, 1993]. The papers listed in the database contain either numerical data or general information, comments, and review articles and are part of the collection of the Data Center on Atomic Line Shapes and Shifts at NIST. The following search categories are included: chemical element, stage of ionization, broadening mechanism, experiment, theory, word in title, author, and year of publications. This database is patterned after the existing NIST Web-based bibliographic database on atomic transition probabilities. Our plan is to add all 5000 earlier references from the Data Center collection to the database in order to provide a complete set. (J. Fuhr and H. Felrice)

■ **X-ray Spectroscopy on EBIT.** In collaboration with Russian researchers who have developed expertise in fabricating high quality spherically curved crystals of mica and quartz, we have deployed these crystals as the heart of a new type of x-ray spectrometer for use on an Electron Beam Ion Trap (EBIT). This spectrometer has an advantage over all other x-ray spectrometers previously used on an EBIT: the ability to acquire spectra with both high light collection efficiency and relative insensitivity to source position. This simultaneously addresses the two main factors that have limited the precision of previous measurements on EBIT's-photon statistics and calibration systematics. Demonstration spectra from neon-like barium (Ba^{46+}) and helium-like argon (Ar^{16+}) were obtained, paving the way for future high accuracy measurements. In parallel with this work, progress has been made using traditional NIST x-ray spectrometers to determine wavelengths in hydrogen-like and helium-like vanadium ions with an absolute accuracy that rivals the best previous measurements in this region of the one- and two-electron isoelectronic sequences. With an accuracy of 20 to 30 parts per million, these results critically challenge calculations of the atomic structure of highly charged ions, particularly considering recent significant revisions involving higher order quantum electrodynamic corrections. Our work is proceeding in collaboration with researchers from Australia; a preliminary report was recently submitted for publication, and a final report is under preparation. (J. Gillaspy and L. Hudson)

■ **Highly Charged Ions Used to Pattern Surfaces.** Masked ion beam lithography using highly charged ions (Xe^{44+}) was demonstrated by the EBIT team by exposing a silicon wafer coated with a commercial resist material

(PMMA). Subsequent chemical development of the resist revealed the imposed pattern—a regular array of hundreds of 1 micrometer wide squares with better than 100 nm edge resolution. Atomic force microscopy was also used to image single ion impact sites, which appear as 24 nm wide holes in the surface. Although PMMA is widely used in the community of ion-beam lithography researchers, this is the first time that highly charged ions have been used and that atomic force microscopy has been deployed to reveal the effect of a single ion on this material. Some related work has just been completed using Xe^{44+} ions to pattern an advanced ultrathin resist consisting of self-assembled monolayers of alkanethiolates. (L. Ratliff, J. Gillaspy, and R. Minniti)

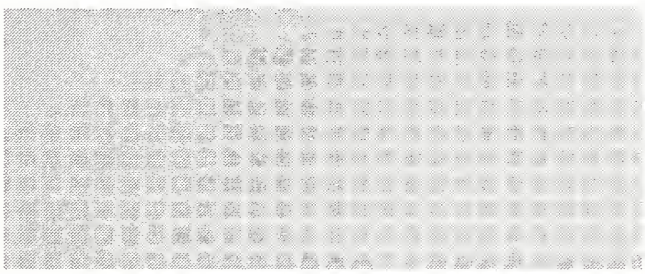


Figure 2. Portion of an array of squares produced using highly charged ions to expose a self-assembled monolayer resist.

■ **Characterization of the GEC-ICP RF Plasma Source.** This new class of high-density, low-pressure plasma sources is becoming increasingly important to meet the demands of reducing the critical dimensions of etched structures in the semiconductor industry. As the wafer diameters used in etching increases, monitoring and control of plasma uniformity become increasingly important. A new diagnostic technique for plasma uniformity measurements based on 2D optical tomography has been developed for vacuum chambers with restricted optical access. Optical tomography determines the two-dimensional distribution of plasma species in a plasma from line-integrated measurements, such as optical emission measurements or laser absorption measurements, without assuming radial symmetry of the plasma. This technique has been applied to optical emission measurements from the GEC-ICP RF Plasma Source. Several conditions creating radially asymmetric plasmas have been identified, such as gas flow rate, proximity to the induction coil, and feed gas composition.

Operation of the GEC-ICP RF Plasma Source with pulsed RF power has been investigated. By momentarily interrupting the power to the inductive coil, the properties of an inductively coupled plasma can be significantly altered. With electronegative gases commonly used in commercial etching reactors, interruption of the RF power results in a rapid loss of electrons creating a decaying plasma composed of only positive and negative ions. The resulting ion-ion plasmas have the potential to improve etching performance and reduce surface damage on wafers. The decay and growth of the plasma during pulsed power operation of the GEC-ICP RF Plasma Source has been measured using a new, intensified CCD camera. In argon/oxygen mixtures, when the RF power is turned back on, the plasma first ignites as a dim capacitive discharge before switching back into a bright inductive discharge. (E. Benck and J. Roberts)

■ **Plasma Radiation.** We have recently completed the rebuilding of the NIST FT700 ultraviolet Fourier transform spectrometer. The FT700 spectrometer is a unique resource. It has a wavelength coverage from the visible down to approximately 200 nm and a resolving power of 10^6. (An upgrade of the interferometer optics is currently underway to extend the range to 140 nm.) We have used the new spectrometer to make accurate measurements of spectral line intensities and branching ratios in the ultraviolet in Kr II, Mn II and Xe II. The measurements provide data to test recent, sophisticated, atomic structure calculations and are needed in the diagnostics of laboratory and stellar plasmas. (U. Griesmann, K. Dzierzega, R. Kling, and W. Wiese)

■ **High-Accuracy DUV and VUV Index of Refraction Measurements.** As part of a collaborative project with MIT Lincoln Laboratory, SEMATECH, and the NIST Optical Technology Division, we have made the highest accuracy ($\sim 7 \times 10^{-6}$) measurements of the index of refraction, its dispersion, and its temperature dependence, of fused silica and calcium fluoride near 193 nm. These numbers are being used by the semiconductor electronics industry for the design of the transmissive optics of photolithographic steppers using 193 nm ArF excimer laser excitation. These will be used for the fabrication of 0.18 μm minimum-feature-size integrated circuits, scheduled for large-scale production by the U.S. semiconductor industry beginning in

2001. For future-generation integrated circuits, stepper manufacturers are designing steppers based on 157 nm F_2 excimer laser excitation and calcium fluoride optics. Responding to requests from all major stepper manufacturers, we have made the only measurements of index of refraction (to 7×10^{-6}), its dispersion, and its temperature dependence, of calcium fluoride near 157 nm. [J. Burnett, U. Griesmann, and R. Gupta (Div 844)]

■ **Ultracold Collisions in Metastable Xenon.** We have investigated the effects of spin polarization and quantum statistics on ultracold inelastic collisions in metastable xenon. We found that, contrary to expectations, the rate of inelastic ionizing collisions was not at all suppressed by spin-polarizing the sample of atoms. The spin selection rules that might be expected to apply are voided by a molecular effect where the spins "lock" to the molecular axis instead of the laboratory axis. The atoms strongly depolarize during the collision, so that the initial polarization has no effect on the outcome. This result calls into question the likelihood of using metastable rare gases other than helium for Bose-Einstein condensation. We also measured the spin-polarized collision rates for fermionic and bosonic isotopes of xenon, and found a significant decrease in the collision rate of the fermions at low temperatures. This is directly ascribable to quantum statistics and the Pauli exclusion principle, which prevents two identical fermions from occupying the same state. This measurement is the first clear observation of quantum statistical suppression in cold collisions.

Because ultracold atoms move so slowly, it is possible to observe the temporal dynamics of collisions. By preparing excited state atoms with a short pulse of laser light and measuring the arrival time of the ions produced in collisions, we were able to study the collision process in detail. We have observed the acceleration of the atoms on the attractive intermolecular potential and have clearly observed collisions that include the decay of the excited atom to the ground state during the collision. We have also been able to time-resolve the optical shielding process, where light excites a pair of atoms onto a repulsive molecular potential, preventing a short range, ionizing collision from occurring. (S. Rolston, C. Orzel, and S. Kulin)

■ **Large Bose-Einstein Condensation of Sodium in a TOP Trap.** We have created a large Bose-Einstein condensate (BEC) of sodium atoms in a time-averaged orbiting potential (TOP) trap. A TOP trap is a magnetic trap consisting of a quadrupole magnetic field and a constant magnitude, rotating, bias field. The arrangement of our fields produces a tri-axial potential that is well matched for loading from the nearly spherical clouds of laser cooled atoms. We have developed two new strategies for evaporatively cooling atoms to Bose-Einstein condensation. The first strategy involves evaporative cooling using rf, with the atoms initially trapped in a quadrupole field. This is then followed by rapidly transferring them into the TOP trap and further cooling of the sample to condensation, again using rf-induced evaporation. The second strategy involves starting with atoms in the TOP trap and evaporatively cooling the atoms with the "circle-of-death" (the zero field region rotating around the center of the trap) all the way to condensation. Both strategies produce approximately the same number of final condensate atoms, about 3×10^6, at a BEC transition temperature of 1.2 μK. (L. Deng, E.W. Hagley, K. Helmerson, M. Kozuma, R. Lutwak, J.-H. Müller, W.D. Phillips, S.L. Rolston, and J. Wen)

■ **Bragg Diffraction of a Bose-Einstein Condensate.** We have coherently split and deflected a Bose-Einstein condensate (BEC) of sodium atoms using Bragg diffraction by a moving, optical standing wave, comprised of two counterpropagating laser beams with a frequency difference. The condensate atoms, initially at rest, will simultaneously absorb photons from the higher frequency laser beam and be stimulated to emit photons into the lower frequency beam acquiring several units of photon momentum in the process. Hence the momentum transfer is uni-directional and coherent. The increase in kinetic energy of the Bragg diffracted atoms comes from the energy difference between the absorbed and emitted photons from the two different frequency laser beams.

In our experiments we start with an adiabatically expanded BEC with no discernable thermal fraction present. The momentum spread of the condensate atoms released from the trap is much less than the momentum of a single photon. We then expose the atoms to a short pulse of the moving, optical standing wave while they are either still in the TOP trap or shortly after releasing them from the trap. We detect the momentum transferred to the atoms from the diffraction process by taking an absorption image after a sufficient time delay, such that the various atomic wave-packets with different momenta have spatially separated. Figure 3 shows first, second and third order Bragg diffraction of Bose condensed atoms, corresponding to momentum transfer of 2, 4 and 6 times the single photon momentum. We have observed up to 6th order Bragg diffraction. The direction of the momentum transfer can be reversed by changing the sign of the frequency difference. We have observed first order Bragg diffraction of 100% of the condensate atoms. (L. Deng, E.W. Hagley, K. Helmerson, M. Kozuma, R. Lutwak, W.D. Phillips, S.L. Rolston, and J. Wen)

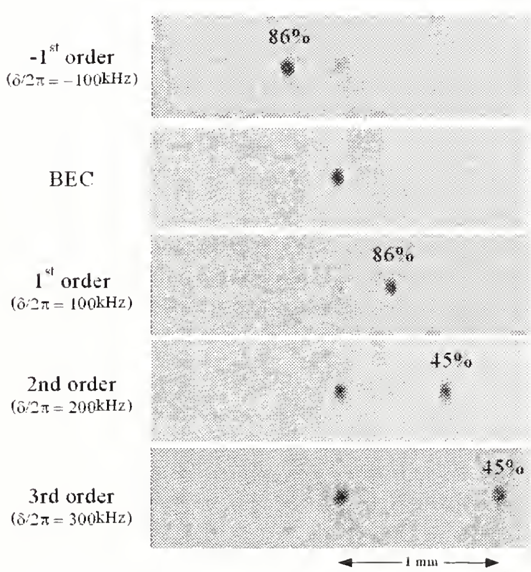


Figure 3. 1st, 2nd and 3rd order Bragg diffraction of a BEC by a moving, optical standing wave.

■ Non-Linear Matter-Wave Optics with Bose-Einstein Condensates. Due to the relatively strong influence of the atom-atom interactions in a Bose-Einstein condensate, non-linear effects in matter-wave optics can occur. These non-linear effects are analogous to non-linear optical wave phenomena. Specifically, the theory predicts that an interacting condensate is analogous to optical waves interacting with a third order, non-linear medium. The resulting process from such an interaction is 4-wave mixing. In 4-wave mixing, three waves are sent into a non-linear medium and a fourth wave emerges. We have observed a similar phenomenon with matter-waves, where the non-linear medium is the interacting atoms themselves. (See also the Division's cover picture.)

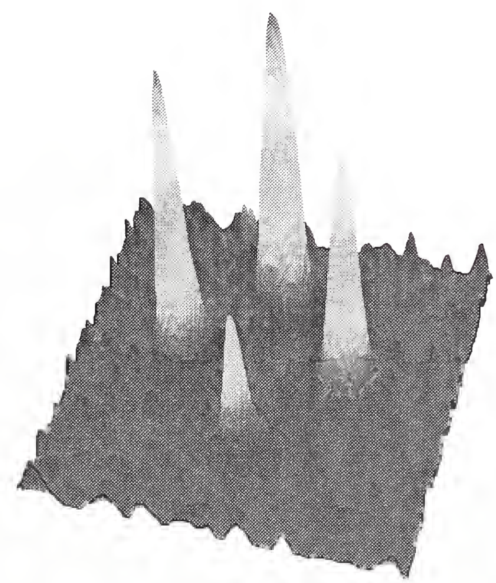


Figure 4. Image of the distribution of atoms resulting from 4-wave mixing of matter waves.

In order to observe the generation of a fourth wave due to 4-wave mixing, the three incident waves must have the appropriate momenta to satisfy energy and momentum conservation. We use two Bragg diffraction pulses to produce condensates in the three appropriate momentum states to observe 4-wave mixing of matter-waves. The pulses are applied rapidly enough that the atoms in the three momentum states still overlap. The non-linear interaction between the atoms produces a fourth state with a different momentum. Figure 4 is an image of the distribution of atoms resulting from 4-wave mixing of matter-waves, taken after the different momentum states have spatially separated. This represents the first example of non-linear atom optics. The smallest peak is the fourth matter-wave, generated by the 4-wave mixing process. We have observed up to 12% of the initial condensate atoms appearing in the fourth wave. We have also confirmed that the process depends on the product of the densities of atoms in the three initial momentum states. (L. Deng, E.W. Hagley, K. Helmerson, W.D. Phillips, S.L. Rolston, and J.E. Simsarian)

■ More Precise Value of the Neutron Mass. The absolute wavelength of the gamma-ray produced in the reaction $n+p \Rightarrow d+\gamma$(2.2 MeV) was measured with a relative uncertainty of 2×10^{-7} using the NIST ILL GAMS4 crystal diffraction facility at the Institut Laue-Langevin in Grenoble, France. This wavelength measurement, expressed in energy units and corrected for recoil, is the binding energy of the neutron in deuterium. A previous crystal diffraction measurement of the deuteron binding energy has an uncertainty 5 times larger than this new result. The neutron mass follows directly from the reaction expressed in atomic mass units: $m(n) = m(^2H) - m(^1H) + S(d)$ where $S(d)$ is the separation energy of the neutron in deuterium. The uncertainties of the atomic mass difference, $m(^2H) - m(^1H)$, and the new determination of $S(d)$ are 0.71×10^{-9} u and 0.42×10^{-9} u, respectively, where u is unified atomic mass unit. The new, more precise value for the neutron mass, $m(n) = 1.008\ 664\ 916\ 37(82)$ u, has an uncertainty which is ≈ 2.5 times smaller than the previous best value. [E. Kessler and M.S. Dewey (Div 846)]

■ New High-flux X-ray Diffractometer/ Reflectometer. Using a novel optical design, a new x-ray analysis facility has been built which provides a peak count rate of 10^7 photons/s for the study of materials of interest to the semiconductor industry. Industry standard 200 mm wafers can now be examined using the new instrument. Films as thin and light as 1.5 nm of Si_3N_4 and as thick and dense as 100 nm of Pt have been successfully characterized by this facility. The high counting rate also allows large batches of films to be studied in short order. Recent materials of interest characterized for various industrial partners include SiO_xN_y, $Ba_{(1-x)}Sr_xTi_yO_3$ (Fig. 5), Ta_2O_5 and TaN_x. (S. Owens, J. Pedulla, and R. Deslattes)

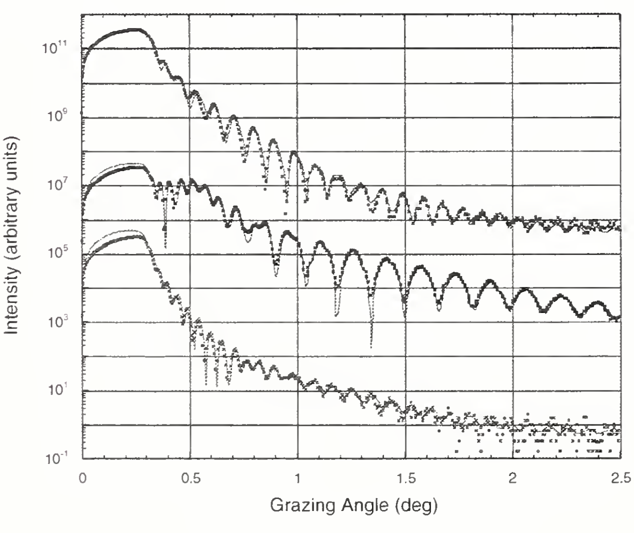


Figure 5. Grazing incidence x-ray reflectivity data and modeled fits for $Ba_{(1-x)}Sr_xTi_yO_3$ thin films.

■ Development of Thin Film Reference Materials. Accurately characterized, highly uniform thin films are in great demand for fluorescence measurement calibration. Using a Dual Ion Beam Assisted Deposition facility, a wide variety of materials are being grown with excellent lateral thickness uniformity, high density and low interfacial roughness. These films are characterized in-house by Grazing Incidence X-ray Reflectivity (GIXR) which provides film thickness and interface roughness to 0.1 nm resolution and density to a few percent resolution. Films on 7.5 cm × 7.5 cm float-glass and 7.5 cm diameter silicon substrates are currently being shipped to both internal and industrial partners. (J. Pedulla)

■ Recertification of Si SRM-640b Powder-Diffraction Reference Material. X-ray powder diffraction is a widely used analytical method for which NIST is the world's principal supplier of powder-diffraction reference materials (SRMs). Current inventory and previous certification accuracy are inadequate to future need. In collaboration with the Materials Science and Engineering Laboratory, a major effort has been undertaken to produce and certify a new generation of these reference materials. Diffractometer calibrations and uniformity tests on 30 kg of single-crystal silicon material were completed. This material was crushed and sized to form the new silicon SRM-640c; its packaging and certification await selection of a surface stabilization process. Meanwhile, we have re-certified the previous material, silicon SRM 640b, with a relative uncertainty close to 1×10^{-6} Å. (J.-L. Staudenmann, L. Hudson, and R. Deslattes)

■ Picometer Heterodyne Interferometery Demonstrated. Heterodyne Michelson interferometry is the most widely used technique for accurate displacement measurements. Its accuracy has traditionally been limited to a few nm by well-known periodic systematic errors arising from optical crosstalk. Brute-force improvement of a traditional interferometer in our laboratory brought the amplitude of the periodic error down to 500 pm in 1992, but in order to go beyond this level, new techniques are required. We have recently developed and demonstrated two new schemes for doing heterodyne interferometry in which the amount of optical crosstalk can be greatly reduced. In one such scheme, the residual periodic error has an amplitude of 20 pm.

More recent results with the second scheme suggest that the periodic error is even lower, and in fact beyond our ability to measure. In addition, we have demonstrated a new digital phase meter with a 10 kHz bandwidth capable of splitting optical fringes by a factor of 32,000. (C.-M. Wu, J. Lawall, and R. Deslattes)

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 x-ray and visible spectroscopy. While continuing our collaborations with distant experts (primarily from Australia and Russia) as much as possible, we plan to develop new in-house spectroscopy instrumentation and methods and increase inter-group work within NIST to lessen our dependence on guest researchers. This should allow us to accelerate our progress in providing atomic data to critically test developments in atomic structure calculations for highly charged ions. With our new FTS instrument, we shall pursue analyses of complex spectra and branching ratio measurements, reaching from the near UV into the infrared with greatly improved data acquisition and analysis. With precisely characterized plasma sources, we shall determine transition probabilities for spectral lines of light elements with much increased accuracy, making use of state-of-the-art data acquisition techniques.

Our new VUV Fourier Transform Spectrometer will extend our ability to carry out accurate measurements of atomic branching fractions into the VUV with much improved efficiency of data acquisition and analysis. We have also developed a new tungsten strip radiometric standard lamp with a sapphire window that will enable us to extend our branching fraction measurements with the IR-VIS-UV FT spectrometer further into the IR.

■ **Critical Evaluation, Compilation and Dissemination of Atomic Data.** Our critical data compilation work will proceed vigorously with tabulations of spectroscopic data, i.e., wavelengths, energy levels, and transition probabilities, for elements of atomic numbers Z=1 through 36, and with the improvement 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.

Our multiyear effort to produce a new, all-Z tabulation of x-ray wavelengths will be expanded on both the theoretical and experimental fronts. The calculations of x-ray wavelengths, a major component of this effort, are being extended to include absorption edges and the n=4 shell; weaker transitions are being included in the data base. Both the low Z ($Z<20$) and the high Z ($Z>90$) elements show poorer agreement between theory and experiment than is found in the central region. In both cases there are weaknesses in the experimental framework that need to be addressed by new precision measurements.

■ **Nanoscale Systems.** We are developing the large-scale computational techniques needed to study many-particle interacting quantum systems in complicated three-dimensional geometries. Our multiband models allow us to accurately describe a wide range of complex nanostructures. We will complete our implementation of realistic tight-binding models for quantum dot nanostructures. Close-packed, high-density, dot arrays that can now be made are essential to take advantage of optical nanostructures in optical device applications. Novel optical and photonic properties are expected for dots that are strongly coupled and create a quantum dot solid. We will begin to model the properties of these quantum dot solids for their use as a new class of materials.

We will improve our expertise in operating our new UHV scanning probe microscope in conjunction with the EBIT ion beamline in order to obtain single atom resolution on the surface of semiconductors and other materials more reliably, and to facilitate our progress in studying the fundamental characteristics of ion-surface interactions as a function of ion charge. In addition, we will bring our earlier preliminary study of the x-rays emitted during ion-surface bombardment to maturity.

In this growth-oriented area, we plan to improve modeling of diffuse scattering from complex layer structures, undertake still further development of our measurement technology, and become more closely involved with microelectronic manufacturing problems. We expect contributions to this expanded effort to include: addition of an outstanding theorist (visiting scientist appointment), third-stage refinement of front-end optics on our high performance thin film diffractometer, and demonstration of advanced control of thickness profiles in graded spacing x-ray optics. Externally, enhanced visibility and effectiveness of our structure measurements are opening the way to obtaining additional support, and an increasing variety of industrial and academic collaborations.

Near-field optical microscopy shows great promise for achieving subwavelength optical resolution. Theoretical models of NSOM images are essential to utilize NSOM for nano-scale metrology. Our computational tools to model and interpret NSOM images, including finite difference and element approaches, mode expansion techniques, and scattering techniques, will be integrated into a general computational package to best exploit each technique. Specific applications include tip design and optimization, scanning of evanescent fields by small metal tips, and photon scanning tunneling microscopy. We will begin to develop models for diagnostic imaging of optical waveguides, for which NSOM offers a new probe for measuring defects in structure and coupling efficiencies into, from, and between devices.

■ **Laser Cooling and Atomic Manipulations.** We plan to coherently couple atoms out of a Bose condensate and study the coherence properties of condensates and of atoms coupled out of a BEC. This work will be directed toward producing a beam of atoms with de-Broglie wave properties similar to that of light from a laser. We will continue to work with the Electron and Optical Physics Division and the Quantum Processes Group of this Division to construct theoretical models for the BEC and the output-coupling process for the atom laser.

We hope to combine our expertise in optical lattices and BEC to make optical lattices in which a large fraction of (or all) lattice sites are occupied by atoms in the lowest motional energy level. One application of such cold, dense lattices would be to quantum computers, and we intend to pursue some of the proposals to manipulate qubits in optical lattices.

We plan to study ultracold plasmas and Rydberg gases in the metastable xenon system. These atoms, when cooled, trapped, and excited to high-lying Rydberg states, constitute a "frozen" Rydberg gas. In such a system the nuclear motion is essentially frozen on the time scale during which important interactions can occur. For still higher-lying Rydberg states, the electron orbit size becomes larger than the internuclear spacing and the system should become a neutral plasma, with the electrons being free to move about as in a metal. The coupling parameter that characterizes these ultracold plasmas is several orders of magnitude larger than in any previous cold plasma system.

The ultracold collisions program will begin a series of pulsed-laser, photoassociation experiments to investigate the time-dependent dynamics of photoassociation reactions. We will also investigate the "molecule laser," using photoassociation in a BEC to generate a coherent beam of molecules.

The optical tweezers team will begin to study the time scales of bio-adhesion, using antibodies and antigens and neutrophil systems. Adhesion is an important aspect of many biological systems and is relevant to such issues as infection and cancer metastasis.

Quantitative, predictive models of atom interactions in cold atomic gases and Bose-Einstein condensates will be extended to time-dependent magnetic or optical fields and tight confinement of the atoms. Applications include condensate manipulation, cold molecule production, and quantum computing using neutral atom optical lattices. We will continue to develop time-dependent methods for characterizing matter waves and atom lasers derived from Bose-Einstein condensate sources.

■ **Metrology.** 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. This apparatus will implement 2-D Raman velocity-selection and/or cooling. This will improve the performance both of the fountain clock and of a microgravity space clock.

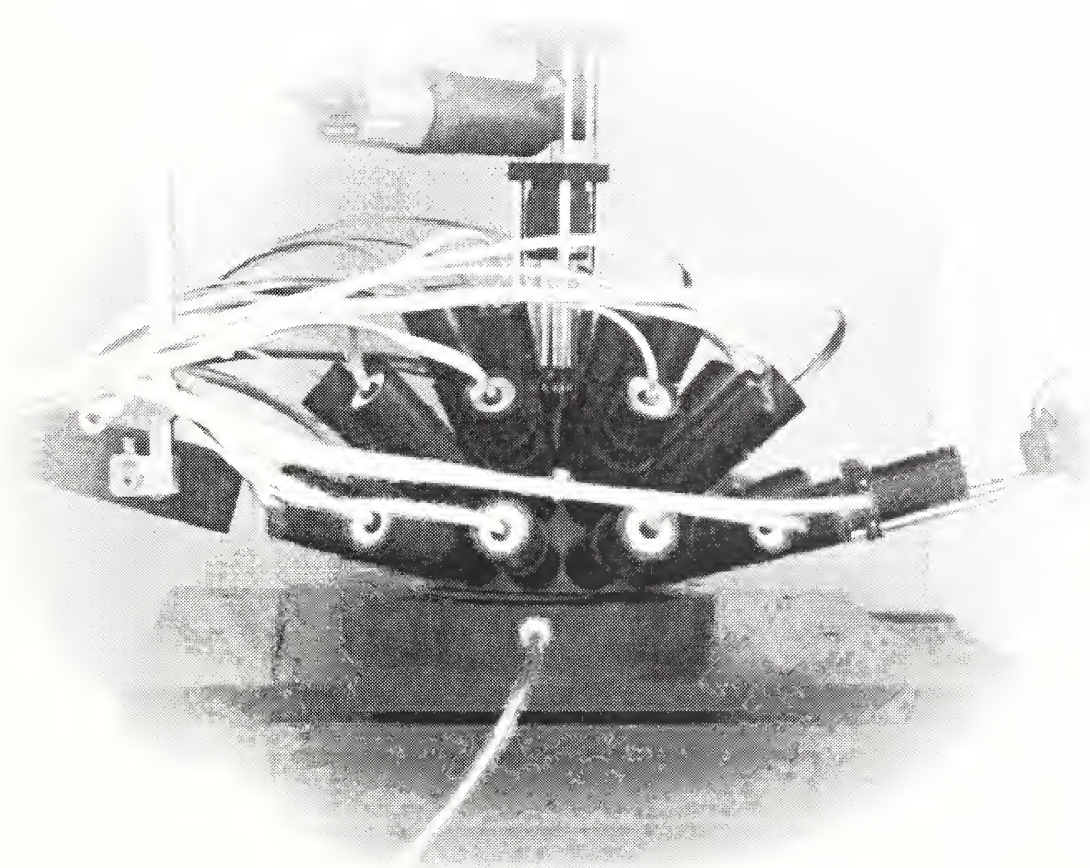
Our efforts in displacement metrology will be concentrated in the sub-atomic displacement measurement project, which is developing a measurement system integrating heterodyne Michelson interferometry, Fabry-Perot interferometry, and x-ray interferometry. The second phase of this project will extend the range from 5 cm to 50 cm using the expertise acquired in the current phase.

To meet the demands of the semiconductor lithography industry for more accurate index of refraction measurements (1×10^{-6}) of fused silica and calcium fluoride near 193 nm for the final designs of 193 nm steppers, we are developing a refractometry method based on interferometry. This method employs the technique of spectrally-resolved, white light interferometry, using a Deep/Vacuum-UV Fourier transform spectrometer.

■ **Plasma Diagnostics.** Optical tomography will continue to be developed as a diagnostic technique. Improvements will be made in the optical emission data acquisition system to significantly reduce data acquisition time in order to demonstrate the potential use of optical tomography as a real-time or in-time plasma uniformity sensor for plasma process control. In addition, IR laser absorption or mm wave absorption measurements will be investigated for their potential as process control diagnostics, either in combination with the optical tomography for plasma uniformity or as monitors of radial species densities.

Work will continue on the pulsed power operation of the GEC-ICP RF Plasma Source. A variety of temporally-resolved, diagnostic techniques such as optical emission, IR laser absorption, Langmuir probe, electrical, and mass selective ion energy measurements will be combined to characterize the pulsed power plasma behavior. This information will then be applied to the development of the necessary metrology necessary for process control of high-density pulsed plasma sources. □

OPTICAL TECHNOLOGY DIVISION



Overleaf

Hemispherical Polarized Light Scattering Instrument. The scanning hemispherical polarized light scattering instrument analyzes the light scattered by defects and particles on silicon wafers. A laser beam is focused onto the sample, and 28 systems, each having a polarizer in front of a detector, collect the light scattered into different directions. In one configuration, the polarizers can be aligned so that the instrument is blind to scatter from microroughness, thereby improving the detection efficiency for smaller defects and particles.

OPTICAL TECHNOLOGY DIVISION

MISSION

The Optical Technology Division of the Physics Laboratory provides high quality national measurement standards and support services to advance the use and application of optical technologies spanning the ultraviolet through microwave spectral regions for use by diverse customers in industry, government, and academia. In addition, the Division has the institutional responsibility for maintaining two SI units: the unit for temperature, the kelvin, 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 and by publishing descriptions of the advances in techniques in appropriate scientific journals;
- 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 in scientific and engineering endeavors.

To accomplish these goals in a responsive manner, the Division works closely with industry, academia, 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, provides leadership in identifying future needs, and provides calibration services and produces Standard Reference Materials (SRM) to accommodate the current needs of the optical technology community. Additionally, the Division staff are active in professional societies and participates in the activities of the Council for Optical Radiation Measurements (CORM) and the International Commission on Illumination (CIE). The Division staff lend their expertise and participate in documentary standards activity through the American Society for the Testing of Materials and other documentary standards organizations. As a result of these interactions, the Division gains valuable insight on identifying the emerging needs of American industry which must be met to support the growth of quality manufacturing efforts for the broad range of products that utilize optical technology in some stage of their production. Meeting these needs assists American industry in maintaining a competitive posture in the world market.

ORGANIZATION

The Division employs approximately 50 staff members including scientists, engineers, and support personnel, and maintains a mix of research, development, and measurement support services. It is organized into five groups and operates under a project structure that promotes collaborations across group administrative lines. Each of the projects has an assigned technical leader who is responsible for planning and accomplishing the technical objectives of the project. The project's responsibility often crosses group or divisional lines and requires coordination and priority setting. The project structure is sufficiently flexible to allow for redirection of resources to accomplish newly identified program objectives and has proven to be a useful management tool for assigning responsibility and tracking progress.

CURRENT DIRECTIONS

■ **Calibration Services.** The Division provides calibration services and measurements in the areas of 1) radiance temperature, 2) spectroradiometric sources, 3) optical properties of materials, 4) photometry, and 5) spectroradiometric detectors. During the past year, the calibration staff worked very hard to reduce the time in progress from 180 days to 90 days in response to a request from customers for a more rapid turn-around in calibration services. The Division has completed an ambitious program to implement the International Quality Standard for Calibration Laboratories, the ISO Guide 25, in all of its calibration services during the past several years and has developed a protocol for an annual assessment of its quality system.

■ **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 responsively. A second, high-sensitivity cryogenic radiometer is the basis for the Low Background Infrared (LBIR) facility, which provides calibrations, research and development for high-sensitivity infrared sensors. At the Synchrotron Ultraviolet Radiation Facility (SURF), a new monochromator-based cryogenic radiometer has been established as a part of the effort to furnish a spectral radiance power scale based upon SURF's output and to serve as a calibration facility for transfer standard detectors. Development of new radiometers incorporating superconducting technology and high T_c materials is an important component of the cryogenic radiometry program. A second generation HACR is being developed to improve utility and sensitivity.

Transfer-standard detectors used throughout the Division are calibrated with the cryogenic radiometers. The Division also develops transfer standard detectors to enable the high-accuracy radiometric scales to be propagated to other laboratories. Transfer standards are being developed at near-infrared and ultraviolet wavelengths that will substantially improve the calibration uncertainties in these areas.

■ **Photometry, Colorimetry, and Appearance.** Photometry, the science of measuring light with the response function of an "average" human observer, is an integral part of the detector metrology program. The SI unit of luminous intensity, the candela, is maintained using a set of well-characterized, 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. The Division can offer photometric detector characterization to customers as a more direct and stable calibration procedure than the conventional use of lamps as standards. The Division has developed a total luminous flux scale based upon the new candela which should result in lower costs and better calibrations for the Division's customers.

The physical measurement of appearance quantifies attributes of an object's interaction with light. Appearance is generally categorized into spectral (color) and spatial (gloss, texture, etc.) properties of reflected light. Physical measurements of source, object, and reflected light are weighted by CIE tristimulus functions or by standard illuminants for the computation of visual appearance and color. A goniophotometer is under development for the measurement of 20°, 60°, and 85° gloss, and research is underway to develop primary gloss standards. A gloss measuring instrument has been established and a haze measuring instrument is under development. In the area of colorimetry, the Spectral Tri-function Automated Reference Reflectometer (STARR) is being used to develop a measurement assurance program with industry standard color tiles and to perform research into the instrument attributes necessary for highly accurate colorimetry for future calibration services. The primary goals of the program are development of reference instruments and standards for current appearance measurement technologies and eventual development of new measurements and standards to more accurately capture visual appearance.

■ **Spectrophotometry.** The Division maintains reference instruments for both spectral reflectance and transmittance, as well as specialized instruments for industrial optical measurement problems. The reference instrument for spectral reflectance produces a variety of measurement standards, while the two reference instruments for regular spectral transmittance continue to be refurbished after moving into a new laboratory. A specialized instrument for visual diffuse transmission density is fully operational, while an instrument for characterizing retroreflection is being designed. In addition to satisfying internal NIST needs, these facilities provide calibrations for a wide range of customers.

■ **Optical Scattering Metrology.** Mechanisms by which material properties and surface topography affect the distribution and polarization of light scattered from surfaces are studied to develop sophisticated measurement methods for use in industry. A hemispherical scanning optical scatter instrument has been designed and constructed to perform as a working prototype of a scanning inspection instrument. The design was based upon knowledge acquired by using a previously constructed goniometric instrument and upon extensive theoretical calculations and simulations. By polarization discrimination, this instrument can be blind to microroughness, thereby increasing its sensitivity to particulate contamination or subsurface defects.

■ **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 microscopes, but by the size of the sub-wavelength aperture or tip used as a probe. Well-characterized microscopes and compact light sources have been constructed and methods to determine resolution are being developed. 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.

■ **Nonlinear Spectroscopy at Interfaces.** The nonlinear spectroscopy of Sum Frequency Generation (SFG) is uniquely sensitive to molecular structure at interfaces. Our new implementation of SFG relies on femtosecond lasers and nonlinear optics to generate ultrafast, spectrally-broad, IR pulses. These are mixed at the interface of interest with transform-limited picosecond visible pulses so that the entire SFG spectrum in the IR region of interest is produced and recorded on every laser shot, rapidly obtaining vibrationally-resonant, SFG spectra with high resolution and signal-to-noise. Spectroscopic measurement applications include characterization of electronic structure at buried epitaxial interfaces, assessment of the structure and quality of thin films, and vibrationally-resonant SFG of molecules at liquid interfaces, organic films such as self-assembled monolayers, and biological interfaces such as cell membranes or biomimetic membranes in physiological, aqueous solutions.

■ **Analytic Spectroscopy.** Spectroscopic 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) establishing and disseminating spectroscopic databases to facilitate choices of monitoring frequencies and inversion of measurements to extract concentrations; (2) developing quantum-mechanical Hamiltonians that provide convenient and concise representations of spectroscopic data and their validation; (3) making laboratory spectroscopic measurements to provide accurate frequency and intensity information for instrument calibration; (4) developing 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) working with industry to transfer these technologies and to assess needs for new optical chemical analysis technologies, standards, and data.

■ **Terahertz Spectroscopy.** Several new avenues of research are being pursued involving spectroscopy in the far-infrared spectral region and the use of two recently developed, distinctly different, frequency sources. One source is based on the use of an ultrafast photomixer that was developed at MIT's Lincoln Laboratories. It is a solid state device that generates broadly tunable radiation based on the frequency difference of two near infrared lasers. The power output is in the μW regime but it is sufficient for use as a spectroscopic source. The output of the diode lasers that drive this device can be coupled through fiber optics to remote locations. Current work is underway to couple this system to the plasma diagnostics cell in the Atomic Physics Division.

A second area of research involves collaboration with the staff of the Applied Physics Institute in Nizhny Novgorod, Russia. In this work, backward wave oscillators (BWOs) manufactured in Russia are being used to generate radiation from 100 GHz to 700 GHz. The output power of these devices typically is around 10 milliwatts and is also broadly tunable over ~100 to 200 GHz.

HIGHLIGHTS

■ **NIST Rapid Thermal Processing Temperature Measurement Facility.** This project is developing advanced methodologies for making accurate temperature measurements in rapid thermal processing (RTP) tools using radiation thermometers (RT). To achieve the goal of ±2 °C, major emphasis was placed in three areas this year. In order to establish the temperature scale in the tool using a calibration wafer, the radiation thermometers were compared with the NIST thin-film thermocouples (TFTC). When the differences of the RT and TFTC temperatures were plotted against the TFTC temperature for two separate data sets, the results indicated a variation of about ±1 °C between the two data sets. The radiation in the RTP production tools was characterized to explain any differences between radiation and contact temperature scales. Characterization of the radiation environment inside the RTP chamber included three types of modeling with progressively more complex effects. Results from the three models have shown sufficient agreement for validation cases. Actual cases will be further analyzed with these models. (R. Saunders, B. Tsai, and D. DeWitt)

■ **High Heat Flux Sensors Calibration Competence Program.** A major development was the successful commissioning and validation of a spherical blackbody facility to calibrate heat flux sensors up to 100 kW/m^2 at radiant source temperatures of about 1300 K. Extensive experimental studies on Schmidt-Boelter and Gardon heat flux sensors were conducted to investigate the absolute and transfer calibration techniques. The results of the study demonstrated that, for successful application of the absolute technique, it is necessary to account for the heat transfer effects at the sensor surface due to induced flow effects of the hot gas from the furnace. However, the transfer calibration technique presently in use at NIST showed good agreement in calibration over a wide range of convective heat transfer conditions at the sensor surface and also with intercomparison calibration results from the 25 mm Variable Temperature Blackbody primary facility. The success of the transfer calibration technique using the new spherical blackbody suggests its use in future calibration services. (B. Tsai, M. Annageri, and R. Saunders)

■ **Absolute Detector-Based Spectral Irradiance and Radiance Temperature Scale.** The present NIST spectral irradiance scale and radiance temperature scale is based upon the freezing point of gold at 1337.33 K, although the output of a 1000 W FEL spectral irradiance lamp sold as a calibrated source is more closely approximated by the output of a nearly 3000 K high-temperature blackbody (HTBB). The new, proposed scale uses broadband, filtered, silicon detectors calibrated for absolute spectral response derived from the HACR to determine the radiance temperature of a 3000 K graphite blackbody. The spectral irradiance of FEL lamps used as working standards can be directly assigned by comparison to the 3000 K (±1 K) blackbody, and the final uncertainties in the spectral irradiance of issued FEL lamps will be reduced by the new, more direct scale assignment. Preliminary radiance temperature assignments of the HTBB using the old source-based scale and the new detector-based scale are in agreement to <0.5 K at 2500 K and higher temperatures. Work is in progress to issue FEL lamps using the new detector-based scale. Since the filter radiometers are stable over time, the radiance temperature scale can be maintained on the filter radiometers as opposed to maintaining the series of blackbody sources. Recent results show agreement between the absolute detector-based radiance temperature and the current radiance temperature scale to ≤ 0.5 K from 2200 K to 2800 K. This will provide the basis for the radiation temperature scale's reference to a detector base. Work is in progress to extend the comparison to the gold freezing point (1337.33 K). The results will be presented at TEMPMEKO '99. (H. Yoon, C. Johnson, and R. Saunders).

■ **Integrating Sphere System for Absolute Infrared Reflectance, Transmittance, and Absorptance.** A new device and method has been developed for characterizing the optical properties of materials and components in the infrared from 1 µm to 19 µm. The system employs a custom integrating sphere mounted on motorized rotation stages, and is connected to a Fourier transform spectrophotometer. All types of samples can be characterized, but for those that do not scatter light absolute transmittance, reflectance, and absorptance can be determined with high accuracy. The sphere-based absolute method has a number of advantages over other methods commonly used. Primarily, the sphere system is insensitive to beam alteration effects due to attributes of the sample under test.

The integrating sphere system is used as the FTIR Spectrophotometry Laboratory's "reference instrument" in support of both internal Division and NIST projects as well as external programs and customers. For example, it has been used to characterize mirrors in support of the SIRTF (Space Infrared Telescope Facility) and SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) programs. (L. Hanssen)

High-Tc SACR

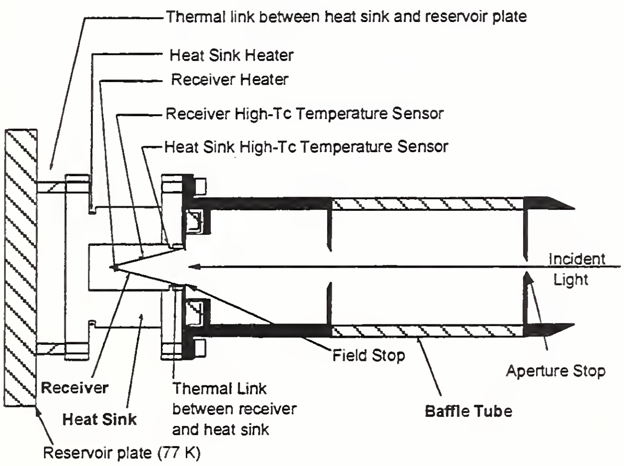


Figure 1. Section view of the high-T_C SACR (T_C = critical temperature; SACR = space-based active cavity radiometer).

■ **Absolute Radiometer Using High-Temperature Superconductors.** Absolute electrical substitution radiometers have been used for several years at liquid-helium temperature by standards laboratories and others for high-accuracy implementation of radiometric scales. Room temperature versions, more convenient though often lacking in sensitivity and accuracy, have also been available for many years. Now a collaboration of NIST scientists from the Optical Technology Division in Gaithersburg and the Electromagnetic Technology Division in Boulder have built and demonstrated a radiometer that strikes a useful compromise between accuracy and convenience by requiring only liquid-nitrogen cooling yet providing adequate sensitivity and accuracy for many calibration needs. This High-Critical-Temperature Space-Based Active Cavity Radiometer (High-T_C SACR) uses extremely sensitive temperature sensors made from thin film $YBa_2Cu_3O_7$, a high-T_C superconductor. By operating the sensors on the resistive edge of the superconducting phase transition at a temperature near 90 K, unprecedented sensitivity for an active cavity radiometer at these temperatures was achieved. For example, an absolute flux measurement of 10 microwatts can be made with a noise-limited 1-σ uncertainty below 0.2%. This level, though not nearly as low as can be obtained with a liquid-helium-cooled device, is acceptable for a wide market of calibration labs that seek easier, cheaper ways of making accurate optical power measurements. The device is shown in Fig. 1. (J. Rice)

■ **TASSII.** A team, led by the Naval Research Laboratory (NRL) and including NIST's Optical Technology Division staff, was selected by NASA for the Phase B study of the Total Solar Irradiance Monitor (TSIM). This satellite, scheduled to be launched in 2001 and have a five-year lifetime, will orbit the earth at about 600 km altitude and stare at the sun. The major objective is to monitor the solar irradiance (power per unit area) reaching the top of the Earth's atmosphere. Though once thought of as a constant, the solar irradiance has been measured to vary by about 0.1% over the past two decades by instruments on previous satellites. This variability is considered a major enough forcing element of climate variability that NASA plans to continue monitoring this with small satellites. The instrument being designed by the NRL/NIST team, called the Total and Spectral Solar Irradiance Investigation (TASSII), utilizes the latest absolute radiometer expertise contributed by the NIST scientists to achieve unprecedented precision. Furthermore, the planned calibration of TASSII instruments directly against NIST radiometric standards will enable unprecedented accuracy of the solar irradiance measurements. This will be the first time a NIST absolute radiometer is used to measure the solar constant from space. (S. Lorentz)

■ **Theory of X-ray and Optical Absorption Spectra of Solids.** The Optical Technology Division has developed theoretical and computational techniques to predict optical properties of materials from first principles. Work over the last year has included computing the complex dielectric constant of several technologically important semiconductors and insulators and the calculation of x-ray absorption near-edge structure. The critical "new" ingredient of such calculations, now included in much more detail than previously, is the interaction between the electron and hole that are created as a pair during absorption. The techniques that have facilitated computing the above optical properties will continue to be generalized and extended for treating other spectral regions and types of experimental data. Results for silicon are shown in Fig. 2. (E.L. Shirley).

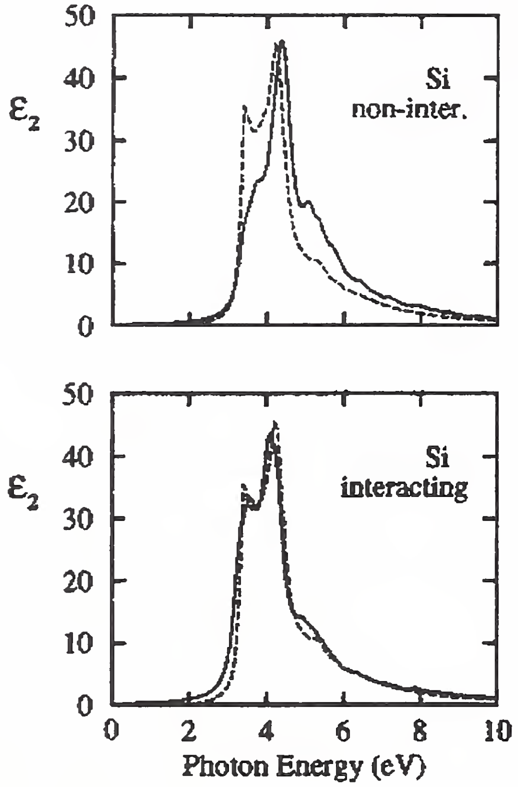


Figure 2. Imaginary part of dielectric constant (ε_2) vs. photon energy as measured (dashed) and computed (solid), with previous results in top panel and recent results in bottom panel.

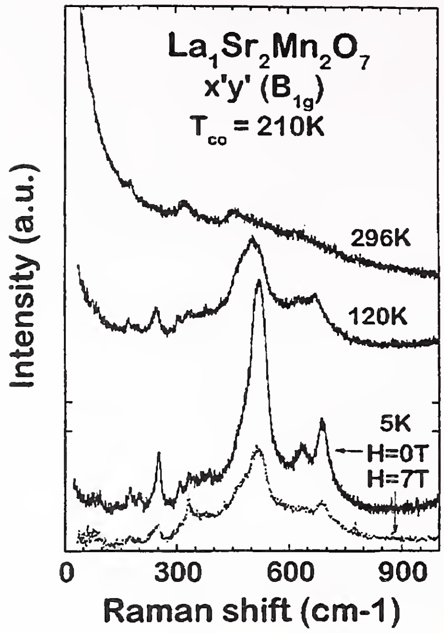


Figure 3. Raman spectra of the layered manganite $LaSr_2Mn_2O_7$ showing the activated peaks for $T < T_{CO}$. Applying a magnetic field H=7 Tesla melts the charge-ordered state.

■ Magneto-Raman Spectroscopy of Novel Condensed Matter Systems. The current effort on magneto-Raman spectroscopy concentrates on the investigation of charge, spin, and lattice excitations in novel materials that are at the forefront of condensed-matter physics research. These studies are conducted over a wide range of temperatures (4 K to 350 K) and magnetic fields (up to 8 Tesla). The materials of current interest are based on transition-metal oxides, which manifest technologically important physical properties such as high-temperature superconductivity in copper-oxides, colossal magnetoresistance (CMR) in manganese-oxides, and ferroelectricity in lead-strontium titanates. This work is done in conjunction with the Materials Research Science and Engineering Center at the University of Maryland. In addition, our collaborators from Argonne National Laboratory and Nagoya University, Japan, provide high-quality single-crystals.

Much of the present work is focused on layered manganites, $La_{n-nx}Sr_{1+nx}Mn_nO_{3n+1}$, since they could provide new insight towards understanding the unconventional, normal-state properties of the cuprates. With the layered manganites, the effects of dimensionality (by varying n, the number of MnO_2 layers) and doping (by changing x) on polaron formation and charge and spin dynamics are explored. Figure 3 shows results for one of the $LaSr_2Mn_2O_7$ s samples. As an example, our observations of Raman signatures of local symmetry-breaking due to polarons and real-space ordering of charges have important implications on models of the CMR phenomenon in the manganites. On a more applied front, a major obstacle in integrating non-volatile ferroelectric memories with silicon-based technologies is the loss of electric polarization upon hydrogen annealing of $Pb(Zr,Ti)O_3$ thin-films. Using Raman spectroscopy, we have demonstrated that hydrogen is incorporated at interstitial tetragonal sites which prevents the Ti ion from switching. (D. Romero and V. Podobedov)

■ Short Course in Photometry and Colorimetry. The Optical Technology Division hosted the first NIST Photometry Short Course on September 10th and 11th at NIST, Gaithersburg, with 19 participants from industry and academia. The number of participants had to be limited due to the experimental sessions provided in the course. The course addressed the need for education and training for photometry engineers and technicians in industry that had been identified recently by CORM, the Lamp Testing Engineer's Conference (LTEC), and other metrology groups within industry. The course was mainly aimed at customers of NIST photometric calibrations and, more widely, technicians and engineers engaged in photometry work in industry. The course covered fundamentals in photometry, radiometry, colorimetry, uncertainty analysis, quality systems, and practical aspects of measurements of luminous flux, luminous intensity, illuminance, luminance, color temperature, and chromaticity of light sources. The course consisted of lectures by NIST photometry experts and an invited lecturer, Dr. G. Sauter from PTB, Germany. Based on its success and future demand, the short course will be offered again next year with an extended schedule. (Y. Ohno, S. Brown, M. Navarro, Y. Zong, and S. Bruce)

■ **New 2.5 m Integrating Sphere for a Novel Luminous Flux Calibration Method.** A new 2.5 m integrating sphere has been built and installed in the NIST photometry laboratory. This sphere replaces the previous 2 m integrating sphere used for many years. The new sphere, designed by the Division's photometry experts, is equipped with a beam scanner and an external source and features a capability for the detector-based measurement of total luminous flux of light sources. The beam scanner, consisting of a small, tungsten-lamp beam source and two rotation stages, allows automatic measurement of the spatial nonuniformity of the sphere responsivity over the entire sphere wall. The external source, consisting of a stable tungsten-halogen source and an aperture/photometer wheel, allows precise calibration of the sphere responsivity based on the illuminance of the introduced light measured by a reference photometer.

This new method makes possible the absolute measurement of total luminous flux using an integrating sphere rather than a costly, large goniophotometer. The Division is helping BIPM (International Bureau of Weights and Measures) to adapt this method to maintaining the lumen in their laboratory also. This new NIST facility now provides calibration of luminous flux of lamps, with no need for traditional working standard lamps and with reduced uncertainty of measurements. (Y. Ohno)

■ **Short Course on Ultraviolet Radiometry for Lithography.** There was a Short Course presented at the SPIE 23rd Annual Meeting held in Santa Clara, CA on Ultraviolet Source and Detector Radiometry in Semiconductor Production Microlithography. The course was taught by R. Gupta (Div 844), J. Burnett (Div. 842), and M. Dowell (Div. 815). The course, geared to the semiconductor industry, included an introduction to the basic concepts of optical radiometry in the deep and vacuum UV, and the applications of UV radiometry to current and future semiconductor lithography tools. The NIST instructors also outlined procedures for maintaining traceability to high-accuracy national radiometric standards. A wide variety of U.S. and Japanese semiconductor industry representatives attended, including those involved in stepper design and manufacturing, laser applications, lithography dose metrology, lithography source designers, and optical engineering. (R. Gupta)

■ **New ACR-based Monochromator System for an Improved Near IR Scale.** We have developed a detector calibration system by using a monochromator system and an ACR (absolute cryogenic radiometer) for the near IR from 900 nm to 1600 nm. With the high accuracy of an ACR, the system achieves detector calibration to an uncertainty of less than 0.5 % in most of this region. We have already measured the responsivity of several InGaAs photodiodes and pyroelectric detectors. These detectors will be used as working standards for the SCF (spectral comparator facility) to reduce the uncertainties in this region for NIST's near IR detector calibration service. Further improvement of this ACR-based calibration system is underway for near UV calibration. (P. Shaw)

■ **Polarized Light Scattering from Dielectric Layers.** The polarization of light scattered by a material can help to identify the cause of that scatter. For a single interface, for example, particles above the surface, defects below the surface, and roughness of the interface each have unique polarization signatures. The application of polarized light scatter measurements was also found useful for characterizing the properties of surfaces with multiple interfaces. Theoretical calculations, the results of which are shown in Fig. 4, demonstrate that defects located at different positions in a dielectric layer on a silicon substrate yield different scattered light polarizations, while roughness at the two interfaces can be distinguished. Furthermore, the polarization can be used to determine the correlation between roughness at two interfaces. Bidirectional ellipsometry measurements were carried out with an air/SiO_2/Si correlated pair of interfaces and yielded results that were in reasonable agreement with the theoretical predictions.

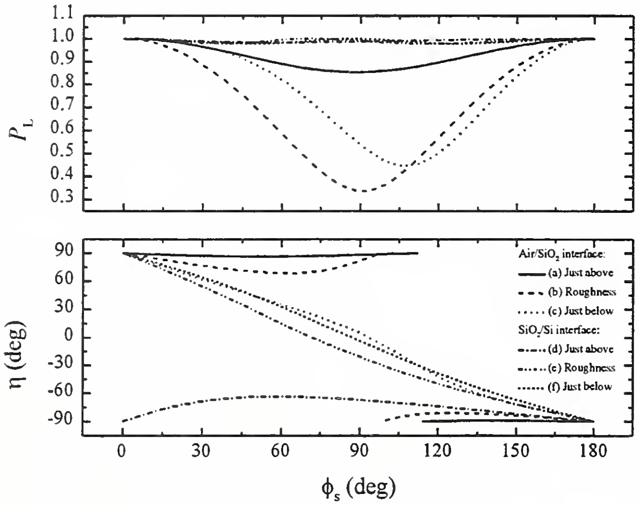


Figure 4. Results of theoretical calculations for the degree of linear polarization, P_L, and the principal axis of polarization, η, as functions of out-of-plane scattering angle for scattering from roughness and defects associated with a 1 μm thick SiO_2 film grown on silicon. The incident light is assumed to be *p*-polarized, and the incident and scattering polar angles are 45°.

These measurements and models help the semiconductor industry detect and identify particulate contamination and defects on silicon wafers. By understanding the light scattered by residual roughness of interfaces, inspection tool manufacturers can increase the sensitivity of their production line inspection tools to these defects. These improvements will allow smaller features to be created reliably on semiconductor wafers. (T. Germer)

■ **Polymer Blends Studied by NSOM.** Thin polymer films are becoming ever more important in optoelectronic and electronic devices. Understanding and characterizing the structure and dynamics of thin films, and especially of thin-film polymer-blends, present challenges associated with the small size of typical features in these films. We are using near-field scanning optical microscopy to meet these challenges. Changes in structure with annealing and with changes in the concentration of conducting polymer have been observed for features as small as a few hundred nanometers. The different optical properties of the two components make detection by either transmission or fluorescence contrast possible, and both mechanisms have been used simultaneously to characterize these materials. An example of the data for a polystyrene/polythiophene blend is shown in Fig. 5. (L. Goldner and J. Hwang)

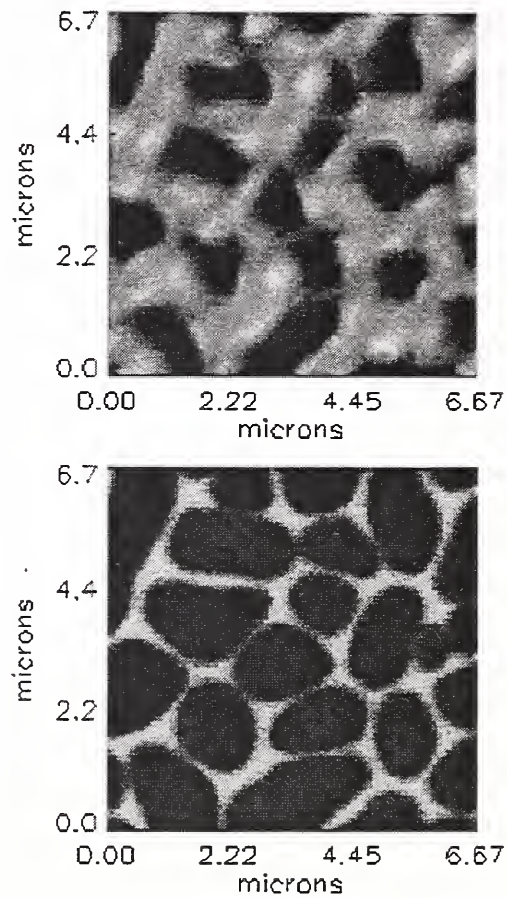


Figure 5. Topographic (top) and fluorescence (bottom) images of a polystyrene/polythiophene film. Note that the topography is correlated with, but not the same as, the domain structure of the film, which is measured more directly by the fluorescence images. Here, the polythiophene is fluorescent.

■ **Vibrationally Resolved Sum-Frequency Generation Studies of Self-Assembled Monolayers Using Broad-Bandwidth Infrared Pulses.** Vibrationally-resolved sum-frequency generation (SFG) spectroscopy is a powerful probe of the molecular order at surfaces and interfaces. In most SFG studies, a narrow-bandwidth IR pulse mixes with a narrow-bandwidth visible pulse through a $\chi^{(2)}$ process at an interface to produce SFG that is not spectrally analyzed. The sum frequency

(SF) spectrum is laboriously acquired by scanning the wavelength of the IR pulse over the vibrational resonances. We developed an alternate approach that obtains SFG spectra with short acquisition times and without wavelength tuning. A nominally 100 fs commercial laser system generates broad-bandwidth (BB) IR pulses that are mixed with narrow-bandwidth visible pulses at the interface of interest. The SF light is collected and dispersed in a spectrograph where a CCD detects all the SF light (spectral range: 600 cm^{-1}) in parallel. This BB SFG approach rapidly produces excellent spectra and in principle, permits ultrafast time resolution.

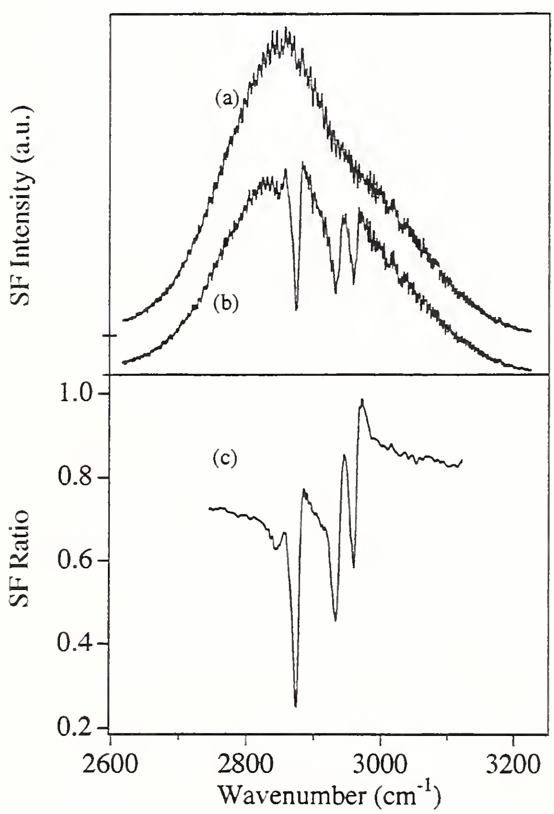


Figure 6. SFG spectrum of an Au film covered with (a) a SAM of d-ODT, (b) a SAM of ODT, and (c) the ratio b/a, the ODT spectrum. Traces (a) and (b) are offset vertically; a line indicating zero signal is shown for each. The spectra were recorded in 60 s.

In collaboration with scientists from the Surface Science and Biotechnology Divisions of CSTL, we demonstrated the BB SFG approach in studies of self-assembled monolayers (SAMs) of normal and deuterated octadecanethiol (ODT, d-ODT) on a Au film. The SFG spectrum in Fig. 6 shows the high signal-to-noise achieved in only 60 s of data acquisition. The spectrum is dominated by the 3 CH stretch features associated with the terminal methyl (CH_3) groups of the SAMs. Features at 2890 and 2930 cm^{-1} due to methylene (CH_2) groups show disorder from the desired all-trans configuration in this sample. SFG spectra of important molecules such as ubiquinone (CoQ) and integral proteins in biomimetic or biological membranes are being studied. (J. Stephenson with L. Richter and T. Petralli-Mallow, CSTL.)

■ **Realization of an IR Spectral Radiant Power Response Scale on a Cryogenic Bolometer.** The Optical Technology Division has developed an IR radiant power response scale for the spectral range from 2 µm to 20 µm for use with a new IR detector comparator facility to provide calibration of spectral radiant power response. The scale operates at much higher sensitivity (input power levels are 10 µW to 20 pW) than typical existing IR scales, while using a detector with a flat spectral response over the entire spectral range. The scale has been realized on a cryogenic bolometer, which accounts for the improved sensitivity relative to detector scales based on pyroelectric detectors. The response of this bolometer has been determined by multiple ties to a primary standard, the NIST High Accuracy Cryogenic Radiometer (HACR). The uncertainty over the entire spectral region is typically better than 0.25%, with the typical uncertainty of an individual measurement made with the bolometer being ~0.8%. This IR scale and the associated IR detector calibration facility have been documented in the recently published NIST Special Publication 250-42. (A. Migdall and G. Eppeldauer).

■ **Spectrometer Identifies Chemical Weapons with Unparalleled Accuracy.** Researchers in the Optical Technology Division have adapted the measurement technology, Fourier-transform microwave (FTMW) spectroscopy, for broad applications in analytical chemistry. As concerns about terrorist activities at home and abroad mount, the development of new measurement techniques for monitoring chemical weapons becomes increasingly important. FTMW spectroscopy utilizes the rotational spectrum of molecules seeded in a cold molecular beam for unambiguous identification of trace amounts of chemical agents in air samples. Via collaboration with the Army's Edgewood Research, Development and Engineering Center, NIST scientists have successfully established a FTMW spectroscopy facility in a surety laboratory in Aberdeen, Maryland where the microwave spectra of nerve agents such as Sarin and Soman have been safely studied. Large survey scans, lasting only 3 hours each, of both Sarin and Soman are shown here. Once the rotational spectrum was assigned, the transition frequencies, accurate to ± 4 kHz, are cataloged into a database for use in conjunction with the FTMW spectrometer for unequivocal identification of the agents. To be complete, the database should contain microwave transition frequencies from synthesis precursors and hydrolysis products as well as the agents themselves. Experiments on the harmless precursors and reaction products were performed at NIST. Possible applications of this technique include tank-mounting the spectrometer for parameter defense during combat or putting the portable instrument in a van for use in inspections for treaty compliance. Future work includes expanding the database by obtaining and analyzing the microwave spectrum of other chemical weapons such as mustard gas and its precursors. The FTMW spectroscopy offers a real-time measurement technique to unambiguously identify and monitor chemical-warfare agents, precursors and reaction products, present in only trace amounts of air. (See Fig. 7) (A.R. Hight Walker and R.D. Suenram)

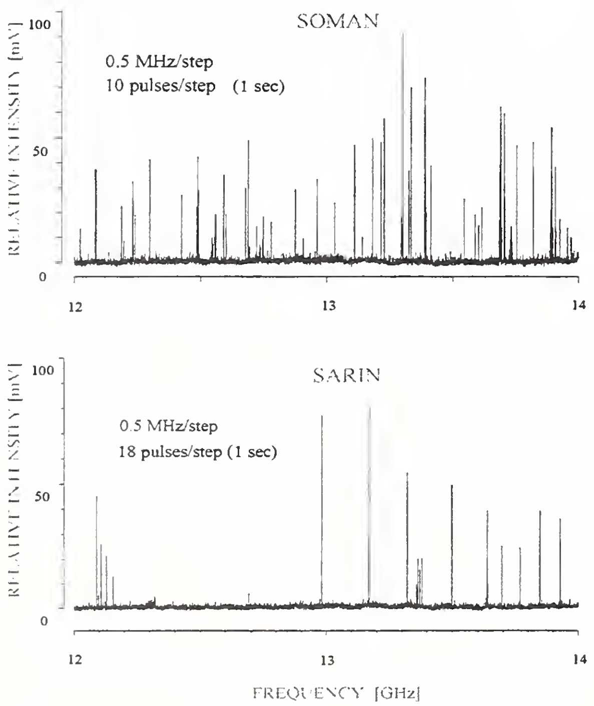


Figure 7. Survey scans of the rotational spectra of sarin and soman in the region of 12 to 14 GHz. These scans demonstrate the uniqueness of the rotational spectra for each compound.

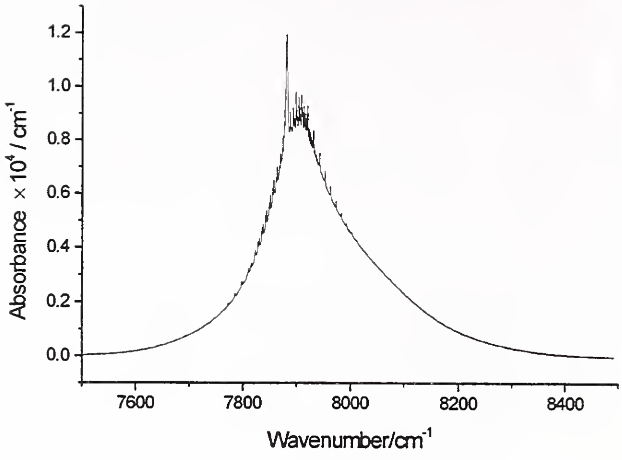


Figure 8. Collision-induced infrared absorption band of O_2 .

■ Laboratory Measurements of the Atmospheric Continuum Absorption by Molecular Oxygen. Laboratory measurements of the molecular oxygen, collision-induced, continuum absorption have been undertaken in the mid and near infrared to provide accurate quantitative data for atmospheric modeling. It has recently been suggested that continuum absorption in the near-infrared to ultraviolet by molecular oxygen may be responsible, in part, for the 10 W m^{-2} to 30 W m^{-2} discrepancy between general circulation models and measurements of the solar atmospheric absorption. Moreover, continuum absorption in the mid-infrared affects the retrieval of NO_2, H_2O, and aerosol concentration profiles by limb-sounding satellite radiometers, such as the High Resolution Dynamics Limb Sounder (HIRDLS), scheduled for launch aboard the CHEM-1 EOS platform in 2002. The laboratory measurements are made with a Fourier-transform spectrometer coupled to a 2 m long variable-temperature, White-type absorption cell. To mimic the integrated product of $\rho^2 L$ along the optical path L, where ρ is the atmospheric density, we multiple-pass the light through the sample to achieve a long-optical-pathlength of 84 m and pressurize the sample to obtain densities up to 10 times the ground-level atmospheric density at 296 K. The figure shows the absorption spectrum obtained for pure O_2 at 296 K at a density 7.5 times larger than the density of O_2 at STP. The sharp spectral features on top of the broad continuum absorption are due to the v=0 – 0 component of the $a\,^1\Delta_g$-$X\,^3\Sigma_g^-$ magnetic dipole band of molecular O_2. The present measurements show that the previous best continuum profiles are in error by 25 % for air as a collision partner and by a factor of 3 for nitrogen as a collision partner. (G.T. Fraser, W.J. Lafferty, C.L. Lugez, and B. Maté)

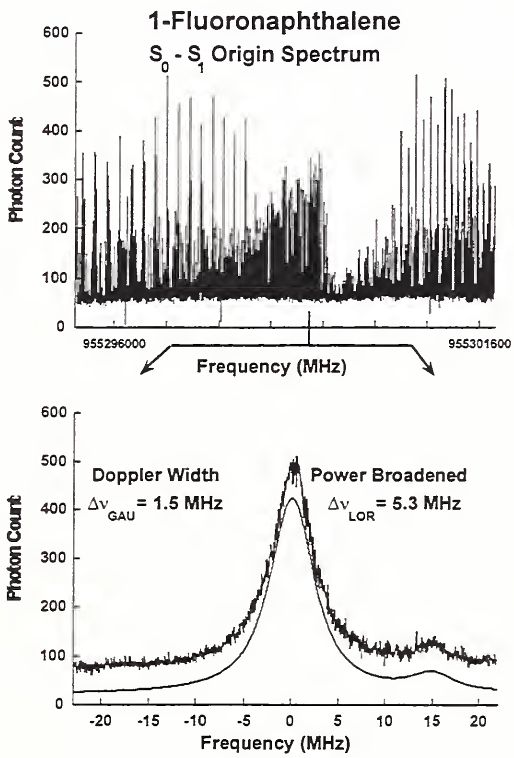


Figure 9. The $S_1 \leftarrow S_0$ origin spectrum of 1-fluoronaphthalene (upper panel) and an expanded portion (lower) in the most congested part of the central Q-branch that illustrates the frequency precision of the scan over a single rotational line in this spectrum.

■ **High Resolution UV Spectroscopic Methods to Probe Chemical Reactions at-or-near Threshold.** We have completed construction of a high resolution UV laser spectrometer capable of resolving, at full rotational state resolution, the structure and dynamics of large molecules and molecular complexes in electronically excited states. Molecules are prepared both rotationally and vibrationally cold by seeding in a cw molecular beam. One meter downstream of the expansion, the molecular beam is crossed by a frequency doubled cw dye laser. The doubled light (~300 nm) is generated in an external ring build-up cavity with 5 to 10% conversion efficiency of the injected 1 Watt of fundamental power. The laser induced fluorescence is detected using a spatially selective light collection assembly coupled to a photon counting/photomultiplier detection system. The sub-Doppler resolving power with narrow band UV excitation (<1 MHz) and the spatial resolved fluorescence filtering is nearly at 1 part in 10^9. Bolometric detection of metastable states and microwave double resonance experiments are also possible. The rotationally resolved fluorescence excitation spectrum of the electronic origin of 1-fluoronaphthalene is shown in Fig. 9. As a demonstration of the frequency resolution and control of this spectrometer, a single rotational line taken from the most congested part of the central **a**-type Q-branch is shown in the bottom panel. Current research projects include the fully quantum-state resolved reactions and near threshold chemistry induced by the absorption of MW, IR and/or UV light. Examples are proton transfer reactions in acid-base molecular complexes and oxygen atom/ozone reactions with vibrationally and/or electronically excited molecules in crossed molecular beams. (D.F. Plusquellic and R.D. Suenram).

FUTURE DIRECTIONS

■ **Machining Process Metrology and Simulation.** In collaboration with the Manufacturing Engineering Laboratory (MEL) and the Information Technology Laboratory (ITL), the Optical Technology Division was recently funded by the Advanced Technology Program (ATP) to support research on fundamental predictive modeling and simulation of machining processes. The goal is to achieve accurate measurements of the temperature and stress fields near the tool-chip interface in order to validate machining simulations. The validation of the modeling will improve the predictive capabilities of these models, which is in great demand because of rapid progress in machining processes. The Optical Technology Division is responsible for the development of an accurate infrared pyrometer that will be used for non-contact thermometry of the tool-chip interface in test bed experiments at NIST. The range of temperatures to be studied is from room temperature to about 700 K. High spatial resolution and fast response time requirements have led to a design that incorporates an all reflective objective, an x-y galvo scanner, and an InGaAs detector. This Scanning Micro-Pyrometer (SCAMPY) will be radiometrically calibrated using blackbody standards in the Optical Technology Division. The emissivity of the tool and the stock material will also be characterized.

■ **Terahertz Dynamical Measurements of Proteins and DNA.** Determining the time-dependent variation in tertiary structure and molecule-biopolymer interactions is crucial towards obtaining a better picture of the biological function of enzymes, protein-drug interactions and DNA helix transitions. The new THz Competence Program will develop a joint research program involving the Optical Technology Division and the Center for Neutron Research in the Materials Science and Engineering Laboratory. We plan to employ state-of-the-art, pulsed, terahertz (THz) optical techniques and high resolution, neutron scattering, techniques to explore the microscopic, concerted, nuclear motions associated with molecular structural changes over various timescales (picoseconds to milliseconds). It is envisioned that, in FY 1999, alterations to the current, pulsed-THz, laser apparatus will enable acquisition of time sequenced spectra after imparting a sample temperature jump by a laser pulse. Application of modern, molecular dynamics, modeling simulations will be used to aid in the assignment of observed, low-frequency, spectroscopic structure and the origin of their measured, time-dependent changes.

■ **Single Molecules as a Probe of the Local Environment.** The behavior of a single molecule depends on its immediate environment in a way that is not well understood. Single dye molecules adsorbed onto a surface exhibit time-dependent spectra and changes in lifetime presumed to be dependent on the details of the surface in the close vicinity, as well as conformal or positional changes in the molecule or the surface. In principle, it should be possible to use the spectra or lifetime of a single molecule to investigate the nanoscale structure of the surface or film that the molecule is on or in. In order to test this hypothesis and begin to understand single molecule spectra, we are building a confocal microscope capable of imaging single molecules. Test samples consisting of dye molecules embedded in self-organized films will be constructed and the spectra and/or lifetime studied and modeled.

■ **Continuous-Wave Mid-infrared Cavity Ringdown Saturation Spectroscopy.** Cavity ringdown spectroscopy has been shown at NIST and elsewhere to be a sensitive technique for measuring the linear absorption spectra of atoms and molecules in the near infrared and visible at optical pathlengths on the order of kilometers. We have recently extended the capabilities of cavity ringdown spectroscopy to the mid-infrared using a CO_2 laser with tunable microwave sidebands. Molecular vibrational absorption coefficients are orders of magnitude larger in the mid-infrared than in the near infrared or visible. Thus, mid-infrared, cavity ringdown spectroscopy offers the opportunity for significantly increased sensitivity for concentration measurements over near infrared and visible measurements. The large absorption coefficients in the mid-infrared have led to the observation of saturation dips on the absorption lines, which improves the frequency precision of the cavity ringdown measurements by more than a factor of 10. In addition, measurements of the linewidths of the saturation dips, which arise primarily from power broadening, furnish a method for the absolute determination of transition moments without knowledge of species concentration. Cavity ringdown spectroscopy thus offers exciting potential for determining the absolute absorption coefficients of many unstable molecules.

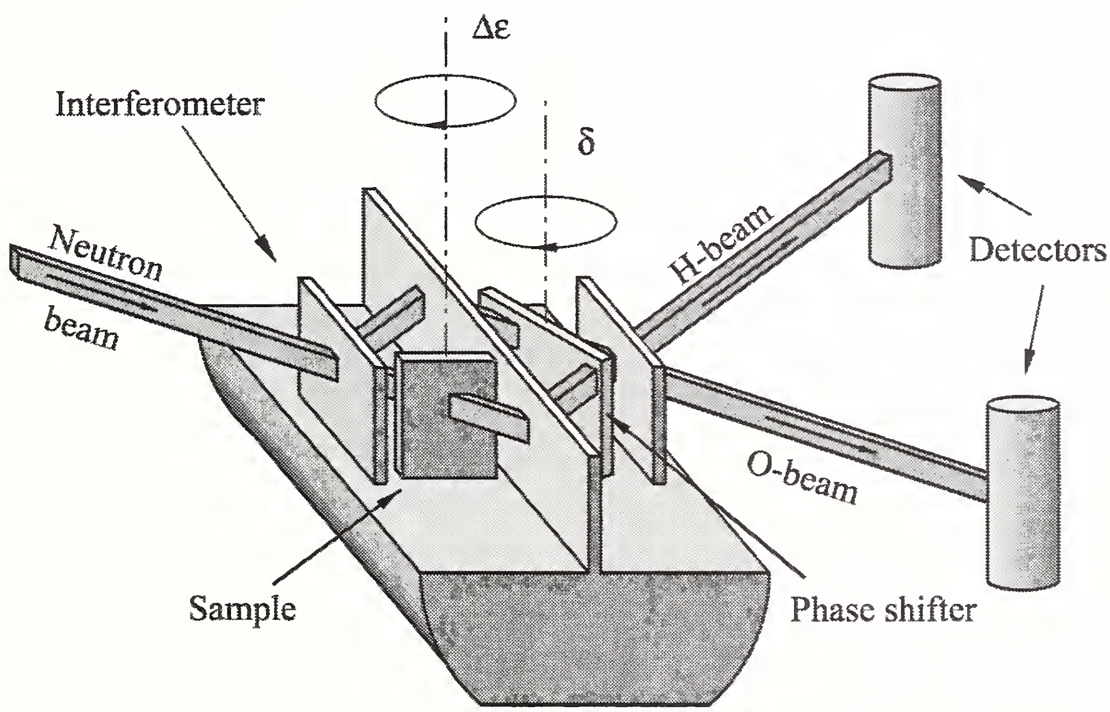
■ **Spectral Irradiance and Radiance Calibrations with Uniform Sources (SIRCUS).** A reference calibration facility is being developed to realize a detector spectral irradiance response scale directly against the High Accuracy Cryogenic Radiometer (HACR). This high accuracy, detector-based scale will be the basis for the illuminance (candela), the color temperature, the radiance temperature, and the spectral radiance response scales of NIST. High performance, transfer- and working-standard radiometers will be developed to realize the irradiance response scale for the UV, VIS, NIR, and IR ranges. The monochromatic source is being realized with stabilized tunable lasers and different size integrating spheres. This versatile, high intensity, radiation source, in addition to the collimated beam geometry, can be used as a point source and/or a large area Lambertian source. The point source geometry and the inverse square law will be utilized to further minimize the illuminance scale uncertainties. The Lambertian sources will be calibrated against the standard irradiance meters. Standards quality radiance meters, calibrated against the Lambertian sources will provide the spectral radiance response scale. A new facility for spectroradiometric source calibration is being designed that will utilize detectors calibrated on SIRCUS.

■ **New Source-based Radiometry Beamline at SURF III.** Synchrotron radiation from SURF has been used as an accurate standard light source for NIST because of its predictable nature. With the upgrade of SURF II to SURF III, this facility will further improve its accuracy as a light source to an unprecedented level. To fully utilize SURF for source-based radiometry, we are developing a new, white-light beamline for SURF III. This beamline will allow unobstructed synchrotron radiation to irradiate detectors (such as spectrally dispersed radiometers) to measure their response. These radiometers are then used to intercompare synchrotron radiation with other standard light sources, such as blackbody radiation, arc lamps, and FEL lamps. The intercomparison between SURF and other NIST standard light sources can improve and maintain NIST scales, especially in the ultraviolet region where SURF has higher radiant power than any other standard light sources. The new beamline can also be used as a general facility for absolute light source calibration.

■ **Development of a Second Generation Cryogenic Radiometer: HACR 2.** A new cryogenic radiometer with a lower uncertainty and greater dynamic range is being developed to replace the present absolute standard, HACR, as the basis for NIST optical calibration scales. The improvements designed into HACR 2 are its operation at 2 K to reduce the noise in the temperature measurements, its operation over a greater dynamic range to avoid nonlinearity corrections to the calibration transfers, and a receiving cavity with a horizontal geometry to facilitate calibration transfers. The dynamic range of HACR 2 will be from 1 μW to 1 mW with an intended uncertainty of 0.01% or better. The fully automated HACR 2 facility will be sharing the laser resources of SIRCUS and be able to provide calibrations at wavelengths from 180 nm to 11 μm. By designing HACR 2 to operate at the power levels of other optical facilities, to be accessible to the wide range of laser resources, and to ease the method of calibration transfers, the overall uncertainty in the optical calibration scales based on the cryogenic radiometer is reduced.

■ **UV Radiometry for Semiconductor Lithography.** A new UV Fourier Transform Spectrometer is nearing completion and will be used to characterize the index of fused silica and calcium fluoride with a target accuracy of 1 part in 10^6. The UV FTS will also be used to characterize the refractive index of purge gasses (such as nitrogen at 157 nm) with an accuracy that is consistent with the needs of the stepper manufacturers which has not been previously been measured. Efforts are being made to upgrade the goniometric refractometer and measure the refractive index of calcium fluoride to an accuracy of 1 part in 10^5. Various photodetectors will be characterized and their stability towards irradiation from an excimer laser operating at 193 nm and at 157 nm will be measured. An improved UV responsivity scale will be realized with the use of synchrotron radiation from SURF III in conjunction with a cryogenic radiometer. □

IONIZING RADIATION DIVISION



Overleaf

The Neutron Interferometer. The neutron interferometer uses "mirrors" of single-crystal silicon to split and recombine a neutron beam. A sample placed in one of the possible neutron paths can shift the neutron phase and create an interference pattern in the recombined beam. A very large variety of experiments in fundamental neutron physics, quantum mechanics, materials science, and phase contrast imaging can be performed with the neutron interferometer. The neutron phase shift is sensitive to both electromagnetic and nuclear properties of the test samples.

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 in the programs of the Council on Ionizing Radiation Measurements and Standards (CIRMS).

ORGANIZATION

The Division employs about 50 scientists, engineers, technicians and secretaries. Activities include fundamental research, applied research, and a wide variety of measurement services. The group structure consists of three technical groups: Radiation Interactions and Dosimetry, Neutron Interactions and Dosimetry, and Radioactivity.

CURRENT DIRECTIONS

■ **Absorbed Dose Standards and Calibrations.** NIST is 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.

■ **New Standards and Calibrations for Low-Energy Photon Brachytherapy Sources.** The recently developed Wide-Angle-Free-Air

Chamber (WAFAC) is the basis for the new NIST standard for air-kerma strength for brachytherapy seeds containing low-energy photon-emitting radionuclides 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 of such seeds. Extensive measurements and analyses have been carried out to firmly establish the new standard and to determine the relationship to the previous standard. A dedicated measurement laboratory has been constructed; new, automated, data acquisition and analysis systems have been implemented; and a new, automated, variable-volume WAFAC has been designed and built. NIST is working closely with the medical physics community and manufacturers to introduce the new standard in 1999 so as to maintain complete continuity in therapy dosimetry planning. An enormous increase in demand for these brachytherapy sources has stimulated the emergence of new manufacturers and new seeds, making the transition to the new WAFAC standard especially timely and underscoring the care with which this transition must be conducted.

■ **X- and Gamma-Ray Source Facilities**. An extensive program is near completion to upgrade the x-ray and gamma-ray facilities used in the NIST dosimetry standards and calibration program. A new 300 kV x-ray generator and a new 100 kV set have been installed in the W-anode x-ray calibration ranges. With the addition of 41 ISO beam qualities and two new U.S. beam qualities, NIST will offer 75 conventional x-ray beam qualities, as well as the 17 mammography (Mo- and Rh-anode) x-ray beam qualities recently established. New data-acquisition/automation hardware and software systems are in development for control of measurements in the W-anode and mammography x-ray ranges, the protection-level horizontal-beam ^{60}Co and ^{137}Cs gamma-ray ranges, the therapy-level vertical-beam ^{60}Co and ^{137}Cs gamma-ray ranges, and the low-energy, photon brachytherapy, Wide-Angle-Free-Air-Chamber Facility. Preliminary planning has been done for the re-sourcing of two ^{60}Co sources: a therapy-level vertical beam, and a high-dose-rate Gammacell used in our radiation-processing dosimetry program.

■ **Standards, Calibrations, and Instrumentation for Environmental Monitoring.** The measurement of environmental surface contamination, particularly around nuclear sites and in environmental remediation, poses an important and difficult problem. This program addresses the metrological needs in this area. Two systems 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 a number of radionuclides for standard development/calibration this year. One of these is ^{177}Lu, a 6.7-day half life beta-particle emitter with potential for use in radioimmunotherapy and bone palliation. We will also continue our efforts to compare short-lived, nuclear medicine nuclides internationally, either through bi-lateral intercomparisons, or through exchanges of calibration factors for ionization chambers.

■ **Radionuclide Metrology Development.** A pulse recording technique has been developed to permit 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 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 become in recent years the most used calibration method, combining speed, simplicity, and high efficiency. However, it must be demonstrated to give results equivalent to primary methods for low energy x-ray emitters, such as palladium-103, and nuclides that decay both by beta-particle emission and electron capture, such as iridium-192.

■ **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 are 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 ANSI Standard N13.30 (Performance Criteria for Radiobioassay) and ANSI N42.22 (Traceability of Radioactive Sources to NIST and Associated Instrument Quality Control), and draft ANSI N42.23 (Measurement and Associated Instrumentation Quality Assurance for Radioassay Laboratories). These three consensus standards call for traceability testing programs that link the quality of operational measurements to the national standards. The Radioactivity Group has established such a traceability testing program for low-level radiochemistry laboratories such as: Westinghouse and U. New Mexico in Carlsbad, NM; Sandia National Laboratory in Albuquerque, NM; and EPA in Montgomery, AL. We anticipate that the program will eventually include both the environmental restoration and radiobioassay communities.

■ **Laser Polarization of Neutrons**. Both the spin-exchange and metastable optical pumping approaches continue to appear promising and worthy of further development. Our high-pressure cells and diode laser arrays are being used as spin filters and/or analyzers in neutron experiments at NIST and Los Alamos. Our low-cost, compact compressor for use with the metastable ^{3}He optical pumping system is already achieving polarization levels adequate for medical, magnetic resonance imaging applications. Additional collaborations in the medical applications are getting started.

■ **Neutron Interferometry and Optics**. The Neutron Interferometer and Optics Facility at the NIST Cold Neutron Research 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 percent at the shorter wavelengths. Experiments include applications for materials science as well as fundamental physics measurements. Very substantial advances are being made in neutron scattering length measurements. Neutron optics developments include phase contrast imaging and high-resolution radiography.

■ **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. Neutron source calibration facilities are undergoing a major renovation. In the next year we will be able to intercompare NBS-I, the NIST RaBe source, with three standard neutron sources obtained from the BIPM. 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 of the NIST Cold Neutron Research Facility is 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 measurements of parity non-conserving spin rotation are competing for beam time.

HIGHLIGHTS

■ **International Comparison of Mammographic X-ray Exposure Standards.** In June of 1998 NIST completed a direct comparison of primary standards for mammographic x-rays at the National Physical Laboratory (NPL) in Teddington, UK. The Ritz chamber, a NIST free-air ionization primary standard used between 20 kV and 100 kV, was compared to the NPL primary standard used for calibrations of mammography x-ray qualities. Good agreement, between 0.4% and 0.6%, was found between the two primary standards. In 1997 an indirect comparison with the German primary standard for mammography showed similar results to the recent NPL-NIST comparison. This indirect comparison was conducted through the use of NIST reference class ionization chambers calibrated at NIST and the German standards laboratory. The results from the calibrations at both national laboratories agreed to within 0.5% for the six different mammographic beam qualities used in this comparison. The NIST primary standard for mammography x-rays, the Attix chamber, was also directly compared with another NIST national standard for low energy x-rays, the Lamperti chamber. The results from the comparison of the two primary standard chambers agreed to within 0.4% for the four molybdenum entrance x-ray beam qualities. (C.M. O'Brien and P.J. Lamperti)

■ **Implementation of ISO Bremsstrahlung and NIST Techniques.** NIST has continued the efforts to implement the photon techniques specified by the International Organization for Standardization (ISO). In addition to implementing the 41 new ISO beam qualities, NIST has responded to the requests of the medical community through the development of several new diagnostic x-ray beam qualities. Development of the diagnostic M80 and M120 beam qualities was identified by CIRMS as a high-priority need and will soon be successfully completed. Calibrations to the ISO beam qualities and the diagnostic beam qualities will be available upon the completion of an evaluation of the correction factors for the primary standards used to measure these new beam qualities. A spectral determination of all new beam qualities will be used to verify the half-value layers of the newly established beam parameters. (C.M. O'Brien, P.J. Lamperti, and S.M. Seltzer)

■ **International Comparisons of Low-Energy X-ray Primary Standards.** Low-energy x-ray comparisons of two NIST primary standards were conducted at both the National Physical Laboratory (NPL) in Teddington, UK, and at the Bureau International des Poids et Mesures (BIPM) in Sevres, France, in the summer of 1998. The NPL-NIST 1998 low-energy portion of the comparison involved a series of air-kerma measurements with both the NIST Lamperti and Ritz free-air chambers and the NPL 1 cm^3 standard chamber. The NPL x-ray beam qualities used for the comparison were produced between 10 kV and 50 kV. Agreement was found to be within 0.5%. The diagnostic-energy portion of the NPL-NIST 1998 comparison involved a series of air-kerma measurements with the NIST Ritz chamber and the new NPL high-energy standard chamber at beam qualities produced at 50 kV and 80 kV. Preliminary results indicate agreement to within 0.6%. The BIPM-NIST 1998 comparison included a repeat of air-kerma measurements made in 1966 with the NIST Lamperti chamber. The goal was to replicate the measurement conditions of the 1966 comparison without compromising the experiment. Although charge-measurement techniques have changed since 1966, the beam-quality parameters, chamber apertures and alignment techniques have remained unchanged at BIPM. The five BIPM beam qualities for the Lamperti chamber comparison were produced by a tungsten anode at 10, 25, 30, and 50 kVp. The NIST Lamperti chamber reproduced the results of 32 years earlier to within 0.1%, and agreement with the BIPM standard in this range was found to be within 0.6%. Comparisons of results from the NIST Ritz chamber and the BIPM standard were made at six BIPM tungsten beam qualities produced at 25, 30, 50, 80 and 100 kVp. Preliminary results indicate agreement that varies from 0.4% to 1.0%. (C.M. O'Brien and P.J. Lamperti)

■ **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 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 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. With the help of the Physics Laboratory's Office of Electronic Commerce of Scientific and Engineering Data, a number of the Center's databases can now be accessed on the worldwide web. (S.M. Seltzer, J.H. Hubbell, and M.J. Berger).

■ **Theoretical Dosimetry for Brachytherapy Sources**. Brachytherapy sources, encapsulated, radioactive materials emitting photons and/or beta particles, are used in a variety of therapeutic applications. Such sources include ophthalmic applicators for the treatment of ocular lesions, low-energy photon "seed" implants for the treatment of prostate cancer, and photon- and beta-emitting intravascular sources of various design intended for the irradiation of artery walls to prevent re-closing (restenosis) after balloon angioplasty. Numerous calculations have been done for a wide variety of source designs to determine the spatial distribution of absorbed dose per unit activity in the source to aid in source optimization, to provide basic dosimetric data, and to determine correction factors for measured results. These calculations are done with state-of-the-art Monte Carlo codes, such as ITS, MCNP4b, and EGS4, and with more rapid point-kernel-based methods. (S.M. Seltzer, C.G. Soares, and F. Mourtada)

■ **^{103}Pd Brachytherapy Source Characterization**. There has recently been a significant increase in the demand for low-energy photon, brachytherapy sources used in the treatment of prostate cancer. We are working with source manufacturers and the medical physics community to develop a new standard for the dosimetry of brachytherapy seeds containing the radionuclide ^{103}Pd. Measurement of the air kerma strength of ^{103}Pd seeds is accomplished using the Wide-Angle-Free-Air Chamber (WAFAC). Ionization current measurements using well-ion chambers and K_α photon fluence measurements are also carried out on each seed. Various ratios of these quantities are computed and evaluated for suitability as calibration factors for source manufacturer, quality control measurements and source user, treatment planning. (M.G. Mitch, P.J. Lamperti, B.E. Zimmerman, F.J. Schima, C.G. Soares, S.M. Seltzer, and B.M. Coursey)

■ **Brachytherapy Source Dosimetry Using the Imaging Plate**. The continuing development of new source geometries with lower required activities to achieve desired doses has prompted an investigation of the possible utilization of Fuji plate phosphoimaging to characterize weak brachytherapy sources. The imaging plate contains a photo-stimulable phosphor which "stores" energy from radiation sources. Following exposure, the plate is placed into a reader that scans the plate surface with a laser, releasing photo-stimulated luminescence that is converted into a two-dimensional digital image. A preliminary depth-dose study using a ^{32}P intravascular brachytherapy wire source in an A150 plastic photon showed the ability of the imaging plate to successfully measure dose rates in the μGy/s range, below that accessible with radiochromic film. (M.G. Mitch and C.G. Soares)

■ **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. 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 trans-axial uniformity. In addition, irradiation of planar sheets of film at various depths in water-equivalent plastic was used to construct data sets that 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 was published in *Medical Physics*. The equipment used for these studies was augmented with the addition of an automated, micro-scintillator, detection system and various well-ionization chambers. Use of all this equipment was centralized in a newly refurbished laboratory. We are collaborating with NeoCardia for dosimetry of a ^{32}P wire, with Washington Hospital Center for dosimetry of various sources, and with Radiance Medical Systems for dosimetry of a radioactive balloon source. Collaborations were also begun with Best Industries for ^{188}W/Re wire sources. Funding was received from the National Advanced Manufacturing Testbed (NAMT) Program at NIST for this work, emphasizing the automation of the source handling for the measurements. An international workshop on brachytherapy source dosimetry was organized and hosted by NIST in April 1998. (C.G. Soares and M.G. Mitch, with F.A. Mourtada, T. Wheatley, and R. Densock, Div. 823)

■ **International Gamma Ray High-Dose Comparison**. The national metrology institutes of the United States (NIST), France (BIPM), Great Britain (NPL), Germany (PTB), Italy (INMRI-ENEA), and the International Atomic Energy Agency, have undertaken a high-dose comparison. The BIPM coordinated the comparison and will analyze and publish the results. The protocol was created through consultation with the two issuing laboratories, NIST and NPL. The dosimeters have been processed by the irradiating laboratories and are currently being measured by the issuing laboratories. (M.F. Desrosiers and V. Nagy)

■ **Internet-Based Calibration Services for the Radiation-Processing Industry.** In cooperation with industry, academia and other government agencies, an Internet-based system will be built for fast remote calibration of high-dose radiation sources against the U.S. national standard gamma-radiation source. The new project will be facilitated by the National Advanced Manufacturing Testbed (NAMT) based in NIST's Manufacturing Engineering Laboratory. The new service will deliver immediate calibration results to the industrial customer on-demand at a lower cost. All prerequisites are now present for automating NIST's calibration services on the basis of modern technologies and commercially available products. Once built, the Internet-based transfer calibration process will be the most modern calibration service available and offer many options for expansion into other areas of dosimetry and metrology in general. The new service will entirely redesign the source calibration process to make it faster, less laborious, much cheaper, and, consequently, much more accessible for present and potential customers. (M.F. Desrosiers, J.M. Puhl, and S.M. Seltzer, with T. Vorburger and T.B. Renegar, Div. 821)

■ **Validation of the EPR Method for Tooth Enamel Dosimetry.** The main objective of radiation protection is the development of systems of protection and decision making that help minimize unfavorable consequences of occupational and non-occupational human exposures. To meet this objective, knowledge is required on dose-effect relationships for radiation-induced, stochastic and deterministic effects. Therefore, the acquisition of dosimetric data from populations with chronic exposure is of special interest. Several new sources (Chernobyl, Techa River) for these studies have arisen and are presently underway. Electron Paramagnetic Resonance (EPR) is the only physical method available to retrospective biological dosimetry studies. Validation of the method and rigorous analysis of critical steps in the method have not been demonstrated in the scientific literature. Validation is essential before these data can be used reliably in epidemiological studies from which recommendations are made for occupational exposures. The objective of this work is to validate the EPR-tooth dose assessment method and produce a standardized procedure with well-defined uncertainties. (M.F. Desrosiers, O.F. Sleptchonok, V. Nagy)

■ **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 variety of formulations 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. Using NIST accelerators and with the cooperation of Risø National Laboratory and the Hungarian Academy of Sciences, a study of the energy response of the films confirmed previously published data on alanine. (M.F. Desrosiers, V. Nagy, W.L. McLaughlin, C.E. Dick, and J.M. Puhl)

■ **Production and Characterization of Radioendofullerenes**. An investigation of novel, fullerene-based, delivery methods for radionuclides in medical/industrial imaging and tracing applications is in progress. Radioendofullerenes have radionuclides trapped inside their all-carbon, cage-like structures, isolating chemically reactive isotopes from the environment. The Kratschmer-Huffman method of fullerene synthesis was carried out in a Fullerene Production Chamber (FPC) using high-current arc burning of graphite rods doped with the isotope to be encapsulated. High-pressure liquid chromatography (HPLC) and thin layer chromatography (TLC) prior to identification of various, purified, fullerene species by optical absorption spectroscopy and mass spectrometry. Current studies have focused on the encapsulation of iodine, as it has several medically useful isotopes. Following development and execution of an encapsulation protocol for "cold" ^{127}I, the radionuclide ^{126}I was produced by the reaction ^{127}I(γ,n) ^{126}I upon irradiation of the sample with bremsstrahlung from our MIRF (Medical Industrial Radiation Facility) linac. The radiolabel was identified by MultiPhoton Detection (MPD) and Fuji plate phosphoimaging. Direct encapsulation of the radionuclide ^{125}I has recently been accomplished, and characterization of this new radioendofullerene species is currently in progress. (M.G. Mitch, L.R. Karam, B.M. Coursey, and K.L. Rowley)

■ **Neutron Interferometry and Optics Facility (NIOF).** During the past year a diverse selection of experiments in fundamental and applied physics have been successfully carried out at the NIOF. These experiments have so far resulted in the writing of six articles for publication and have partially satisfied requirements for two separate Ph.D. dissertations. This work has involved collaborations with the U. Missouri-Columbia, the Hahn-Meitner Institute, the U. Innsbruck, the Exxon Research and Engineering Corporation, and the NIST Polymers Division.

One of these experiments was aimed at searching for the recent predictions of quantum entanglement of the nuclear states in a mixture of fluids. The existence of such entanglement would suggest that the neutron refractive index, *n*, of a mixture cannot be calculated from the knowledge of refractive indices for the constituent elements alone. The experiment measured *n* for various mixtures of H_2O and D_2O. Some theorists have predicted a 5% to 10% deviation from the traditional theory due to quantum entanglement of H and D at room temperature. However, the NIOF experimental data agreed with the traditional theory to within the statistical precision of the data, which was of order 0.4%.

The first, successful, neutron interferometric measurement of the mass density of a thin polymer film (thickness <1 μm) was made at the NIOF in collaboration with the NIST Polymers Division. This new technique to measure thin film density is self-calibrating and does not require complex, mathematical modeling of the makeup or surface profile of the film.

The capabilities of the NIOF have been augmented by the addition of a transmission neutron polarizer and a RF gradient spin flipper. This polarizer provides the NIOF with neutron polarization in excess of 98%. This new capability was exploited in an experiment that directly demonstrated the 4π spin rotation symmetry of the neutron wave function under space rotation. This experiment was unique in that the neutron guide field was gently rotated by 180°, allowing the neutron spin direction to adiabatically follow the field. The measured phase shift is strictly due to the rotation of the spin direction since it is independent of both the strength of the magnetic field and the magnitude of the neutron magnetic moment.

A new, neutron diffraction, radiographic and tomographic, imaging setup has been constructed, installed, and successfully tested. Along with this new addition to the NIOF there exists a 2-dimensional, high resolution, CCD, neutron detector. In addition to radiography, many other types of diffraction imaging experiments were performed with this setup. Researchers from Exxon exploited this facility to study hydrogen distribution in operating fuel cells. Researchers from the U. Innsbruck, Austria, studied the diffraction of neutrons (λ=0.235 nm) from macroscopic objects ~0.1 mm in size. Finally, the Neutron Phase Contrast Imaging technique was demonstrated by a high school student, resulting in his recognition as a semi-finalist in the 57th Westinghouse Science Talent Search. (M. Arif, D. Jacobson, A. Ioffe, P. Huffman, T. Gentile, and A. Thompson)

■ **Polarized ^{3}He for Neutron Spin Filters and MRI Applications.** The primary focus of the polarized ^{3}He program is the development and application of neutron polarizers for both condensed matter and fundamental physics. As a spin-off of this technology, the program also includes collaboration with medical researchers in polarized gas magnetic resonance imaging (MRI). A unique feature of the ^{3}He effort is the concurrent development of the spin-exchange and metastability-exchange optical pumping methods. These two methods have different strengths and weaknesses, and pursuit of both allows for a versatile approach to the needs of different applications.

Neutron polarizer tests have been performed with a compact neutron polarizer test facility located on the new NG6 monochromatic beamline. This apparatus has a laser system for on-line, spin exchange, optical pumping of cells, whereas cells polarized by the metastable method are presently transported from another lab to the test facility. For the metastable method, polarized gas is compressed using a modified diaphragm pump.

The first tests of polarizing neutrons have been performed on this apparatus. A spin-exchange cell produced 88% neutron polarization of the NG6M beam with 8.1% transmission. For a metastable-exchange cell, the results were 67% neutron polarization with 18.5% transmission. For both methods, the ^{3}He polarization was 45%; the difference in the results for neutron polarization and transmission are related to the "thickness" of gas.

In collaboration with C. Glinka, J. Barker, B. Hammouda, and J. Lynn of the NIST Center for Neutron Research, we have performed the first application at a U.S. neutron facility of polarized ^{3}He to condensed matter research. The purpose of this test was to evaluate the use of a ^{3}He-based polarization analyzer in a small angle neutron scattering (SANS) apparatus. Conventional neutron polarizers are not practical for this goal because of the relatively high divergence of the scattered beam. The experiment successfully demonstrated the separation of coherent from incoherent scattering using polarization analysis, which had not previously been performed in SANS experiments.

We have performed collaborative experiments in polarized gas MRI with the U. Pennsylvania and the U. Virginia. Until our recent work, there had been no application of the metastable-exchange method to polarized gas MRI. We have obtained four lung images, three of patients with lung disease, by using the compression apparatus to polarize ^{3}He gas at NIST, and then transporting the gas to U. Pennsylvania and U. Virginia. (T. Gentile, A. Thompson, G. Jones)

■ **Asymmetries of the Weak Interaction and the Neutron Lifetime**. During FY98, two different neutron lifetime experiments, one a NIST-led, cold neutron beam experiment, the other a Harvard-led, ultra cold neutron (UCN) experiment, were conducted on our polychromatic neutron beam at the NIST Cold Neutron Research Facility. On our adjacent monochromatic neutron beam, work was begun to calibrate, using a lithium calorimeter, the efficiency of the neutron fluence monitor belonging to the neutron lifetime experiment.

The NIST lifetime experiment utilizes a continuous, cold, neutron beam, a Penning trap to catch decay protons, and a thin foil, neutron fluence monitor to measure the lifetime. During FY98, 11 series of runs were completed. The statistical uncertainty achieved in those runs was an impressive 1.9 seconds. Nevertheless, our greatest success came in a better understanding of the systematic errors that have influenced results in the past. Major problems affecting stability and reliability of voltages in the Penning trap were identified and eliminated. Proton backscattering from the solid state proton detector is another major concern in this experiment. A correction is possible only when the dead layer of the detector has been characterized.

The UCN lifetime experiment exploits three-dimensional, magnetic trapping of UCN produced by inelastic scattering of cold neutrons in a reservoir of superfluid ^{4}He. As the trapped neutrons decay by beta emission, the energetic electrons generate scintillations in the liquid He that can be detected with nearly 100% efficiency. A measurement of the scintillation rate as a function of time is used to determine the neutron beta-decay lifetime. The apparatus was moved onto the beamline late in 1997. Since then two surprisingly strong sources of background have been studied: a constant background rate and a time dependent rate coming from a trapped species other than neutrons. Work is presently underway to remove these signals. The constant background will be reduced by using additional neutron shielding, muon veto counting, and coincidence between two photomultiplier tubes. Indications are that the coincidence method of running will also reduce the trapped signal to acceptable levels. (M.S. Dewey, J. Adams, M. Arif, T. Gentile, D. Gilliam, P. Huffman, D. Jacobson, G. Jones, J. Nico, A. Thompson, and F. Wietfeldt).

■ **Neutron Dosimetry for Reactor Safety Assessment.** The Neutron Interactions and Dosimetry Group provides metrology services and research studies on neutron metrology to the USNRC Office of Regulatory Research in support of their program in nuclear reactor safety assessment. We are presently completing a multinational, round-robin intercomparison of fissionable, neutron fluence monitors of a design currently employed by the nuclear industry for measuring the RPV fast neutron fluence. In particular, the fission reaction in

^{237}Np fissionable dosimeters is especially useful because it monitors a significantly larger portion of the neutron damage spectrum than do other dosimetry materials. However, several complicating factors (e.g., the presence of a substantial ^{233}Pa equilibrium activity) contribute to considerable differences observed in the results for the fast-neutron fluence obtained from neptunium dosimeters, as compared to other dosimeters. From these tests we will be able to specify details for the accurate use of ^{237}Np as a neutron damage monitor. As a complementary study, a round robin test of ^{93}Nb dosimeters is planned for 1999. (J. Adams and D. Gilliam)

■ **Neutron Cross Section Standards.** NIST has played an important role in the improvement of the neutron cross section standards through both evaluation and experimental work. We are leading an effort that will result in a new international evaluation of the neutron cross section standards. This has involved motivating and coordinating new standards measurements, examining the standards database, and pursuing the extension of the standards over a larger energy range. This work has taken place through participation in the U.S. Cross Section Evaluation Working Group and two international committees, the International Nuclear Data Committee and the Nuclear Energy Agency Nuclear Science Committee. An objective is to complete the evaluation in time for the major international cross section evaluation projects to use the improved standards in forming new versions of their libraries.

NIST has continued to maintain a limited experimental role in the measurements of the standards. This role has led to a new, NIST-LANL-Ohio University collaborative measurement of the H(n,n) angular distribution at Ohio University at 10 MeV neutron energy. Preliminary results indicate differences with the most recent U.S. evaluation of this angular distribution. This work was initiated as a result of concern about that evaluation expressed by European standards groups. The H(n,n) angular distribution is one of the most widely used cross section standards. Also, plans are being made for a new measurement of the ^{10}B total cross section at our new, monochromatic, neutron beam facility on NG6. This work will support efforts to improve the $^{10}B(n,\alpha\gamma)$ standard at low neutron energies. (A. Carlson)

■ **Dissemination of National Standards of Radioactivity.** The Radioactivity Group disseminated the national standards of radioactivity as follows: 1) over 500 radioactivity Standard Reference Materials (SRMs) were provided to customers; 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; and 3) over 60 calibrations of customer sources were provided. (L.L. Lucas, J.C. Cessna, and L.R. Karam)

■ **Glow-Discharge Resonance Ionization Mass Spectrometry (RIMS).** Work continued on the development of a glow-discharge initiated, mass spectrometer system that would permit the direct, compositional analysis of soils and sediments for radioactive and non-radioactive elements. The mass spectrometer was upgraded with improvements in the vacuum systems, improvements in the ion collection systems, renovation of the Faraday Cup insertion and control system, purchase and installation of several needed electronic components, and development of software programs for the automatic manipulation of various physical parameters. Tests were performed with the glow-discharge source aimed at maximizing the neutrals-to-ions ratio for cesium. The response of the output to changes in the glow-discharge current, the internal pressure of the argon gas in the source, and source construction and configuration were examined and compared with theoretical expectations. Much work was performed to obtain the optimal setup for resonance ionization with the TiSapph coupled with an Ar ion laser for the ionization stage. The purchase of appropriate optical parts enabled optimal focussing and alignment of the lasers. After these system improvements were made, the effort was turned to developing a RIS ion beam. Cesium was chosen as a first source element partly because of its low ionization potential, which could lead to less demanding proof of principle and, hence, the exploration of optimal conditions on critical parameters. Initially, a RIS response using a thermal ionization source was obtained using a double filament that allowed vaporization of the source material at low enough temperatures to remove mainly the ion component and, at the same time, allow large amounts of neutrals to be produced. Subsequently, a RIMS beam was produced with the glow-discharge source. Work is now underway to optimize the sensitivity and selectivity of this process. (L.R. Karam, J.M.R. Hutchinson, and L. Pibida)

■ **Environmental Radioactivity SRMs for Radiochemical Metrology.** Over the past decades, on the order of 10^{15} Bq of waste have been stored in the oceans by the nuclear countries. Potential contamination by leaking nuclear waste, including the 17 sunken Russian nuclear submarines in the Arctic Ocean, has caused worldwide concern for the exosphere and commercial food chain. The determination of mBq/g levels of radioactivity in ocean sediments is a difficult task. The NIST Ocean Sediment Standard Reference Material (SRM 4357) now serves as the basis for all measurement assurance programs, methods verification procedures, and data comparisons. This SRM was developed using a composite of 0.5% contaminated Irish Sea sediment and 99.5% Chesapeake Bay sediment by weight. Ten radionuclides, including ^{40}K, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, ^{232}Th, ^{238}Pu, and $^{239-240}$Pu, were certified through a comparison study among 20 international laboratories. The mean values were reported for an additional 11 uncertified radionuclides: ^{129}I, ^{155}Eu, ^{210}Po, ^{210}Pb, ^{212}Pb, ^{214}Bi, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, and ^{241}Am. Interestingly, the measurement results for the primordial radionuclides were distributed normally, while those for the anthropogenic radionuclides were best described by Weibull distributions. SRM 4357 will be followed by additional low-level radioactivity natural matrix SRMs. The Ashed Bone matrix was certified in 1998 and will be followed by Rocky Flats soil II (1999) and the Japan, White, and Irish Seas composite Shellfish. (Z.C. Lin and K.G.W. Inn)

■ **Radionuclide Speciation in Soils and Sediments.** Potentially, billions of dollars of remediation costs could be saved and social concerns could be addressed with reliable and interpretable information on the chemical forms (speciation) of the nuclides and their distribution in the environment. The Ionizing Radiation Division will be developing a new series of environmental SRMs for radionuclide speciation. As a first step towards this goal, the Division, in collaboration with Florida State University, is developing a phase-selective, standard, extraction protocol. The future, environmental, radionuclide SRMs will be characterized for radio-plutonium, uranium, thorium, strontium, and cesium species and will be used by those making decisions for risk assessment, selection of cost-effective, mitigation strategies and technologies, and developing and executing long-term monitoring. The effects of critical variables (time, temperature and reagent concentration) of the leaching protocol are being evaluated for selective dissolution of the exchangeable, carbonate, reducible metal oxide, organic, and acid leachable phases. Once the protocol is documented and pilot tested, a network of collaborations will be developed for the future round-robin testing of the protocol and inter-laboratory comparisons for the certification of the future SRMs. (K.G.W. Inn).

■ **^{239}Pu Intercomparison of ICP-MS, TIMS and FTA at µBq Levels.** The goal of this project was to evaluate the state-of-the-art accuracy (precision, and minimum detection amount) for measuring ^{239}Pu in artificial urine by inductively-coupled plasma, thermal ionization, mass spectrometry and fission track analysis in the range of 18 to 278 µBq/sample. This corresponds to about 3 million atoms of plutonium per 200 g sample. The plan for diluting NIST ^{239}Pu SRM from kBq/kg to µBq/kg in artificial urine was developed by NIST and the Yankee Atomic Environmental Lab. With careful selection of reagents, labware, and high precision metrological techniques, the test materials were made, their concentrations confirmed, and samples sent to participating laboratories. Analysis of the data indicated that ICP-MS currently is capable of making quantitative measurements of ^{239}Pu from urine down to the 18 µBq/ sample level within an uncertainty of 20%. Some potential, technical difficulties by some of the participating laboratories include: 1) data transcription; 2) sample tracking; 3) estimation of limits of detection; 4) statistical control over analytical processes; and 5) control of analytical background. A second study is being planned to include interferences in order to assess the technologies under more realistic conditions. (K.G.W. Inn)

■ **Experimental Determination of Dose Calibrator Settings for ^{188}Re.** Rhenium-188 is proving to be one of the most versatile of the radionuclides currently being investigated for use in nuclear medicine. Among the applications being studied for ^{188}Re are bone pain palliation therapy, radioimmunotherapy, radiation synovectomy, and, more recently, intravascular brachytherapy (IVBT) for the prevention of coronary restenosis following balloon angioplasty. Radioassays are normally performed in the clinic using re-entrant well ionization chambers ("dose calibrators") using a dial setting, or "calibration factor," recommended by the manufacturer. Accurate measurements of radionuclides in the clinic or radiopharmacy therefore demand that the correct calibration factor be applied. The dose calibrator settings for the medical radionuclide ^{188}Re (as $^{188}ReO_4^-$) were experimentally determined using solution sources prepared and calibrated by the Radioactivity Group. These new settings result in activity readings 28% to 30% lower than those obtained using the manufacturer's recommended setting. This discrepancy most likely results from an underestimation of the total radiation yield from ^{188}Re decay by the manufacturer when calculating the dose calibrator response to derive the dial setting. This study emphasizes the need for experimental determinations of dose calibrator settings in the geometry in which the measurements will be performed. (B.E. Zimmerman and J. T. Cessna)

■ **A New Technique for Measuring Contained Activity in Balloon Catheters for Use in Intravascular Brachytherapy: Radioassays and Film Dosimetry of ^{133}Xe.** Accurate dosimetry of liquid- or gas-filled balloon catheters for use in intravascular brachytherapy requires accurate knowledge of the amount of contained activity. However, assumptions made in estimating this quantity often lead to serious errors. The Radioactivity Group has developed a technique to make direct measurements of contained activity in balloon catheters using a commercially-available dose calibrator with a modified shielding liner. Xenon-133 was used as a first test, since a gas is expected to provide the most homogeneous distribution within the balloon, without concern for air bubbles that might be present in liquid sources. A special shielding insert was constructed that would leave the balloon exposed, while shielding the dose calibrator chamber from radiation in the catheter. The dose calibrator was calibrated for ^{133}Xe in the appropriate geometries at NIST. The entire assembly was then tested by assaying balloon catheters (3 mm diameter × 20 mm length or 3.5 mm diameter × 20 mm length) for the amount of contained ^{133}Xe. GAFChromic™ film measurements were performed using balloon catheters that had just been assayed for the amount of contained activity of ^{133}Xe and the results compared to Monte Carlo calculations. Because of the low energy of the ^{133}Xe radiation, many source inhomogeneities were evident, leading to large (~50%) uncertainties. Despite this, agreement with Monte Carlo calculations is good and should improve with higher-energy beta-emitters. (B.E. Zimmerman, M.P. Unterweger, C.G. Soares, and S.M. Seltzer, and R.C. Chan [WHC])

■ **Approaches in Intravascular Brachytherapy.** We developed a system of entrapping ^{99m}Tc within liposomes of various charged (positive, negative or neutral) membranes to be used as a possible, technetium-packaging unit for intravascular irradiation (IVBT) after balloon angioplasty (using the Infiltrator™ catheter system). After preliminary labeling of liposomes showed the feasibility of this approach, labeling of liposomes with ^{99m}Tc at the Washington Hospital Center (WHC) was performed. Labeled liposomes were injected into pig models and a time course was followed over three hours for persistence of liposomes at artery sites (both with and without injury). Fuji imaging of excised arteries (with free ^{99m}Tc and ^{99m}Tc-labeled liposomes) showed that ^{99m}Tc-labeled liposomes persisted longer at the application site than free ^{99m}Tc. We have demonstrated that liposome encapsulation of ^{99m}Tc is highly efficient at volumes up to 1 mL and that the liposomes are stable (do not leak) under *in vivo* types of conditions (in presence of serum) although stannous chloride is necessary for efficient encapsulation. Work has begun to determine the feasibility of using other ^{99m}Tc-labelled compounds (Sestamibi™, Ceretec™) in the same system. (L.R. Karam, B.E. Zimmerman, R. Waksman [WHC], and R. Chan [WHC])

■ **Determination of Calibration Factors for the Nondestructive Assay of Pure Beta-emitting Brachytherapy Sources.** Ionization-chamber calibration factors have been determined for two, commercially-manufactured, intravascular, brachytherapy sources: a TiNi-encapsulated ^{32}P source developed by Guidant Intravascular Intervention (Houston, TX), and a stainless-steel encapsulated ^{90}Sr-^{90}Y developed by Bebig Isopentechnic und Umweltdiagnostik GmbH (Berlin, Germany) in collaboration with the Novoste Corp. (Norcross, GA). The calibration factor for the former was derived from ionization current measurements with a Capintec CRC-12 ("dose calibrator") which is the nuclear-medicine community's *de facto* standard instrument, followed by very quantitative, destructive assays of the ^{32}P content in the sources. Similarly, for the former sources, NIST "4πγ chamber A" calibration factors were determined for both bare ceramic and stainless-steel encapsulated source configurations. (R. Collé)

■ Development of Procedures for the Chemical Digestion and Radionuclidic Assay of Encapsulated, Pure Beta-Emitting, Intravascular Brachytherapy Sources. These methods have been applied to two very different types of sources: a polymer-based, ^{32}P-containing source with TiNi encapsulation; and a ceramic-based, ^{90}Sr-^{90}Y source with stainless-steel encapsulation. The internal compositions for both types of sources had constituents that were chemically impervious. The assays involved partial dissolutions (or extractions) followed by 4πβ liquid scintillation (LS) spectrometry (with ^{3}H-standard efficiency tracing) of the resulting solutions. The procedures for the former included provisions for accounting for all possible losses of ^{32}P in the digestion procedure (based on radiochemical tracing experiments), for any unrecovered activity in the remaining source material, and for any residual activity in the solution- and source-handling tools. The procedures for the latter source consisted of extracting a fraction of the ^{90}Sr activity from the ceramic-like material for LS assay, and determining the fraction of unextracted activity by before and after ionization current measurements on the extracted source material. The uncertainties in the assays were typically 2% to 4% for two standard uncertainty intervals. These destructive assays were required for relating radiochromic-film measurements of the absorbed dose spatial distributions for the sources to theoretic dose modeling, and for establishing calibration factors for subsequent, non-destructive, radionuclidic measurements on the sources. (R. Collé)

■ New "Primary" Standardizations of ^{226}Ra and ^{222}Rn. All extant activity standards and calibrations for ^{226}Ra and ^{222}Rn are based on comparative measurements against an artifact radium mass standard (namely the international 1935 Hönigschmid standards and its derivatives). Efforts are currently underway to remove this dependence and to develop and perform primary standardizations for both ^{226}Ra and the ^{222}Rn subseries based on 4παβ LS spectrometry with ^{3}H-standard efficiency tracing. We have successfully employed this new standardization technique to ^{222}Rn, such as for the calibration of the NIST radon-in-water standard generator and for measurements of the polyethylene-encapsulated ^{226}Ra-solution emanation standards (SRM 4968). The techniques are now being extended to the entire ^{226}Ra decay series. Preliminary findings have demonstrated that the method will be able to adequately resolve the ^{210}Pb subseries (i.e., from ^{226}Ra and the ^{222}Rn subseries) in even aged radium solutions. The ability to perform such a resolution is significant in that it will allow direct intercomparisons between the various ^{226}Ra standards issued by NIST over the past 50 years, irrespective of their present degree of radioactive equilibrium between ^{226}Ra and ^{210}Pb. (R. Collé)

■ Standardization of New Tritiated-Water Standards. The calibration of the new, tritiated-water standard, SRM 4927F, by internal-gas counting and liquid scintillation counting is in progress. This standard and the lower activity SRM 4962F will be used extensively worldwide for ground-water hydrology. The standards and their predecessors are and will be used as the basis for a uniform measurement scale for environmental tritium studies. The NIST tritiated-water standards are also used extensively in liquid scintillation counting. A redetermination of the half-life of tritium is also being done. An accurate value for the half-life is very important in extending the useful lifetime of the tritium standards, i.e., the decay of the certified value is not significantly effected by the uncertainty in the half-life value. (L.L. Lucas and M.P. Unterweger)

■ Titanium-44 Half-life. The 1157 keV gamma ray resulting from the decay of ^{44}Ti (and its 3.93 hour daughter ^{44}Sc) has been observed from the supernova remnant, Cassiopeia A. The flux of this gamma ray and the ^{44}Ti half-life would yield a production abundance of the isotope at the time of the explosion. This is an important "data point" for the test of theoretical models of supernova events. Historically, the measured ^{44}Ti half-life values have ranged from 39 years to 66 years, much too uncertain to be useful.

The Radioactivity Group has had ^{44}Ti sources since 1978. The emission rate of the 1157 keV gamma ray from these sources has been measured from time to time with the Group's carefully calibrated, gamma-ray detector systems. These emission rate measurements were carefully assembled and documented. Over the last year, additional emission rate measurements have been made and a half-life (60.7 years, with an estimated standard error of 1.2 years) determined. (F.J. Schima, F.E. Wietfeldt, and B.M. Coursey)

FUTURE DIRECTIONS

■ **Brachytherapy Dosimetry.** An estimated 60,000 brachytherapy procedures are currently performed annually in the US, with a significant growth seen for low-energy photon brachytherapy (^{125}I and ^{103}Pd) in prostate cancer treatment. Moreover, there is the potential for brachytherapy to increase to some 500,000 procedures per year with the advent of intravascular brachytherapy in the treatment of heart disease. Critical to the assurance of absorbed dose in such procedures is traceability to national standards. Early leadership in the dosimetry of beta-emitting brachytherapy sources should be extended toward development of a coherent program for the measurement of absorbed dose in water or tissue for all such sources, including photon-emitting radionuclides.

■ **Industrial High-Energy Computed Tomography.** Our MIRF electron linear accelerator should provide an adequate source for a testbed for high-energy CT applications. With our experience in low- and high-energy CT and the establishment of capabilities at MIRF, we would be able 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 will help position us to contribute to such studies.

■ **Industrial and Therapy Electron-Beam Dosimetry Calibrations with EPR.** Radiation processing by electron beams with energies from about 0.1 to 25 MeV is carried out in an estimated 700 to 1000 facilities, with such use on an increasing path. For therapy applications, NIST maintains a measurement quality assurance program for electron beams with energies from about 6 MeV to 20 MeV, based on Fricke dosimetry. The MIRF electron accelerator has beam energies of 7 MeV to 32 MeV and the electron Van de Graaff has energies from 1 MeV to 4 MeV. With these resources we can address the need for electron-beam calibrations and measurement services for industrial radiation processing and radiation therapy applications. Initial work with graphite calorimetry in MIRF electron beams shows promise for the development of absolute dosimetry measurements for high-energy electron beams and their transfer to alanine/EPR dosimetry systems. Early field tests indicate the suitability of alanine/EPR dosimetry as a replacement for Fricke dosimetry in our therapy electron-beam measurements. Continued development should promote further maturity in the use of alanine/EPR systems as transfer dosimeters, including such important electron-beam applications.

■ **Magnetically Trapped Ultra Cold Neutrons.** In collaboration with physicists at Harvard, 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 ^{3}He from direct optical pumping of metastable ^{3}He 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 collaborations with the U. Pennsylvania, the U. Nottingham, and the U. Virginia.

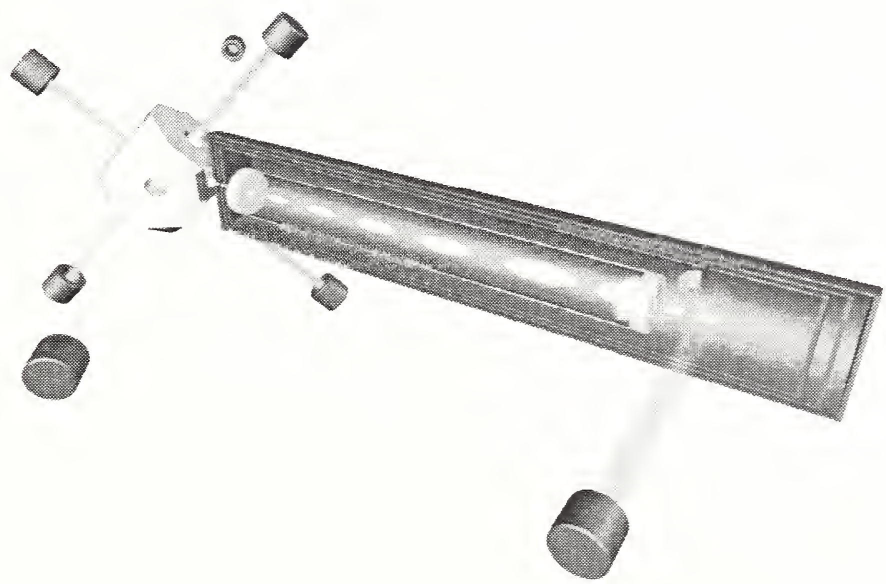
■ **Development and Calibration of Very Low-Level Measurement Techniques.** (i) A fast, inexpensive method for atom counting based on Resonance Ionization Mass Spectrometry will continue to be developed. Although much progress in this program has been made, the sensitivity must be improved by increasing 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.

■ **Development of New Standards for 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.

■ **National and International Intercomparisons in Radioactivity Measurements.** Foreign and domestic National laboratories, in order to maintain the highest possible accuracy of radioactive measurements, must periodically intercompare methods and data related to radioactivity measurements. The Radioactivity Group will continue to participate in a number of national and international intercomparisons in environmental radioactivity metrology and nuclear medicine metrology. In environmental metrology we are working on measurements of ^{40}K, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, ^{232}Th, ^{238}Pu, and $^{239-240}Pu$ with 20 laboratories worldwide and, through our Radiochemistry Intercomparison Program, NRIP, we are working with eight domestic laboratories to meet the demand for traceability. In nuclear medicine metrology we are working on international intercomparisons of ^{133}Xe; recalibration of ^{3}H for international intercomparisons; and submission of standards to the BIPM/SIR program. We continue with our efforts to assist other agencies and private industry to fulfill consensus standards calling for traceability testing programs linking the quality of operational measurements to the national standards.

■ **Low-level Radiochemistry Metrology.** Many tens of thousands of low-level, radiochemical measurements are made annually to support environmental remediation and occupational health programs. To provide infrastructure support for these programs, NIST will focus its efforts into three areas: 1) natural matrix standard reference materials; 2) radionuclide speciation in soils and sediments; and 3) measurement traceability testing. The natural matrix SRM project has certified actinides, and fission and activation radionuclides in soils, fresh-water lake and river sediments, human tissues, and ocean sediment, and is working on additional unique matrices: ashed bone, ocean shellfish, and Rocky Flats Soil-II. A standard protocol for the determining radionuclide partitioning among geophysical/chemical soil and sediment phases for environmental remediation studies is being developed for future characterization of a new family of radionuclide SRMs. The NIST Radiochemistry Intercomparison Program (NRIP) has recently been initiated to provide traceability testing of laboratories engaged in low-level radiobioassay and environmental radionuclide monitoring and remediation. ❑

TIME AND FREQUENCY DIVISION



Overleaf

Schematic of a Laser-Cooled Cesium Clock. This laser-cooled cesium clock is proposed for flight aboard the International Space Station. The microgravity environment of space allows for longer atom-interrogation times, resulting in substantially better clock accuracy, 1×10^{-16} or better. The atoms are trapped and launched periodically (about once per second) from the cubical, atom-preparation region on the left through a microwave cavity to the detection region on the right. In general layout, this is similar to an atomic-beam clock, but it operates in a pulsed mode.

TIME AND FREQUENCY DIVISION

MISSION

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

- the development and operation of standards of time and frequency and coordination of them with other world standards;
- the development of optical frequency standards supporting wavelength and length metrology;
- the 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 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, Network Synchronization, Atomic Standards, Ion Storage, Phase Noise Measurements, Local Oscillators, Laser Frequency Spectroscopy, and Optical Frequency Measurements. 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.

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. The Division is just completing an upgrade of the equipment and power level for WWVB. At a higher output power, these LF broadcasts will become substantially more useful for mobile and consumer applications because the antenna/receiver cost and size are very small. The Division also operates telephone and network time services, the Automated Computer Time Services (ACTS), designed for setting clocks in digital systems. The network (Internet) version of these services now receives more than 4,000,000 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.

■ **Time Scales.** The NIST Time Scale is the flywheel clock system that provides accurate signals for services and applications and 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 advance the performance of the time scale through acquisition of more-stable clocks and improvement of 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.

■ **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}. The Division has also constructed and completed preliminary testing of a cesium-fountain frequency standard. 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.

■ **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 that is the standard for international time coordination. The Division continues to study the two-way time transfer and has completed preliminary tests of GPS carrier-phase time transfer, a method that could become very important for comparisons of the next generation of frequency standards. Both methods offer the promise of higher-accuracy time and frequency comparisons.

■ **Optical Frequency Standards.** The Division develops improved optical frequency measurements important for primary frequency standards, secondary wavelength standards based on atomic-and-molecular transitions, advanced optical communication, analytical instrumentation, and laser systems for 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 develops accurate optical frequency and wavelength references such as the carbon dioxide laser and the calcium-stabilized diode laser. Such frequency references serve as standards in making accurate spectroscopic measurements for industrial and scientific applications. This program is also responsible for the development of advanced, optical-frequency standards needed to support improved length standards and length-measurement methods.

■ **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.

■ **Synchronization for Telecommunications.** The Division has been 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.

■ **Application of Time and Frequency Technology.** The Division is engaged in several activities applying time and frequency technology to important problems in high-resolution spectroscopy and quantum-limited measurements.

TECHNICAL HIGHLIGHTS

■ **Deterministic Quantum Entanglement.** Q. Turchette, C. Monroe, D. Wineland, and other members of the quantum computer project of the Ion Storage Group have recently demonstrated the ability to entangle two quantum particles with high efficiency, advancing the possibilities for reducing noise in stored-ion frequency standards and demonstrating realistic quantum computation. Previously, entanglement of particle states was obtained by post selection from a large number of trial experiments, such as the production of two correlated photons that occasionally occurs when a single photon passes through a special crystal. Such entanglement has proven useful for tests of quantum nonlocality, but entangling a large number of quantum particles--essential for noise reduction in atomic frequency standards and for building a practical quantum computer--becomes much less likely if it is dependent on a probabilistic process. In their "deterministic entanglement" process, a pair of beryllium ions is confined in an ion trap and laser cooled.

Using a predetermined sequence of laser pulses, the internal spin of one ion is entangled with the ions' shared external motion, and the motion is entangled with the spin of the other atom. Entangled spins are therefore obtained "on demand" in each trial. It should be possible to apply the techniques used in these experiments to entangle larger numbers of ions. (Q. Turchette)

■ **Lithographically Fabricated Micro-Traps.** In collaboration with J. Beall of EEEL, C. Myatt of the Ion Storage Group has designed and fabricated the first-generation, lithographic, linear ion trap from a ceramic substrate with gold-plated electrodes. Lithographic fabrication (see Fig. 1) provides for more precise control of dimensions for small traps, and allows construction of the much-more-complex trap arrangements needed for future work on the entanglement of larger numbers of ions.

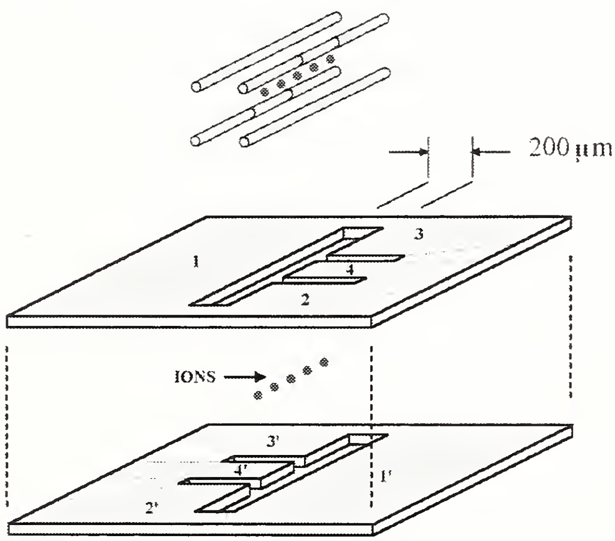


Figure 1. Schematic representation of the lithographic trap. The four rods in the traditional linear trap are shown at the top. In the new trap, shown with substantial separation between the two substrates for clarity, metallization along edges of the slots in the two substrates replaces the rods.

Small numbers of ions have been laser cooled and crystallized in the trap with confinement provided by alternating electric fields at frequencies up to 200 MHz. Independent laser beams have been tightly focussed on each of the two trapped ions, which were separated by about 5 μm, with the off-focus ion receiving only 1/5 of the radiation intensity intended for the other ion. This is important because many of the applications of these entangled states require the separate addressing of individual ions. In addition, the Group has recently shuttled ions along the axis of the trap and separated them by applying pulsed voltages to the electrodes. This technique may relax the laser-focussing constraints for quantum logic gates and individual ion detection and suggests the possibility of multiplexing a more complex array of trapped ions by moving ions between accumulators. (C. Myatt)

■ **Laser Cooling to the Ground State for Two Ions.** B. King and other members of the quantum computer project of the Ion Storage Group have cooled two ions to the ground state of motion, an important step in reducing noise in stored-ion frequency standards and in implementing quantum logic operations on multiple ions. Of critical importance is the heating rate and decoherence of the modes of two-ion motion. The Group found that the center-of-mass modes of the ion pair are heated at a rate of 5 quanta/ms to 10 quanta/ms, similar to previous single-ion results. However, the three, internal, motional modes (stretch and rocking modes) are found not to suffer from heating, up to the level of experimental uncertainty of about 0.1 quanta/ms. This is not unexpected, since the internal modes are immune from the effects of noisy fields affecting both ions equally. The heating results indicate that the (unknown) source is not differential heating, thus ruling out sources such as atomic collisions, field gradients, and certain types of rf-micromotion heating.

These results imply that internal modes are more suitable than any center-of-mass mode for use in quantum-logic or noise-reduction schemes following the general proposal of Cirac and Zoller. However, any logic operation will be affected to higher order by motion in at least one of the center-of-mass modes, so center-of-mass heating remains a concern. (B. King)

■ **Narrowest Linewidth Laser.** In the course of recent efforts to develop an optical frequency standard, B. Young and J. Bergquist, with F. Cruz from Brazil, have demonstrated the narrowest-linewidth visible laser ever built. The ultimate goal of this project is to lock a narrow-linewidth laser to a well defined (282 nm, 2 Hz linewidth) transition in $^{199}Hg^{+}$ ions. The resulting optical frequency standard could be used directly in the optical region, or frequency divided to the microwave region to serve as a traditional atomic clock.

In order to demonstrate the performance of the new laser system, the difference frequency (beatnote) between two laser beams, locked to independent reference cavities on independent isolation platforms, was shown to have a linewidth of 0.84 Hz for an averaging time of 40 s (see Fig. 2). This implies that the linewidth of one of the lasers was less than 0.6 Hz, corresponding to a fractional linewidth of about 1×10^{-15}. The key to this result is the isolation from seismic and acoustic noise and from pressure and temperature fluctuations of the high-finesse, optical cavities used to stabilize the lasers.

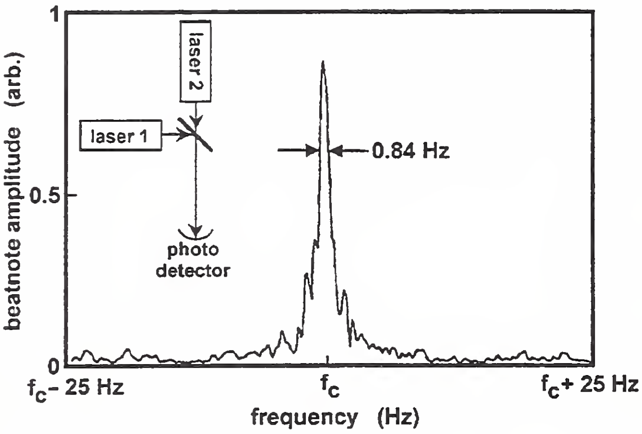


Figure 2. Beatnote observed in mixing the outputs of two separate 563 nm sources. The inset shows the simple experimental arrangement. The data are for a measurement time of 40 s.

The performance of this laser is now better than that needed for a local oscillator for the optical, mercury-ion, frequency standard. Since systematic frequency shifts for the optical-frequency standard are anticipated to be very small, this new standard should perform better than all previous frequency standards. (J. Bergquist)

■ A Diode-Laser, Optical Frequency Standard Using Trapped Calcium Atoms. C. Oates, L. Hollberg, and guest researcher F. Bondu have developed and tested an all-diode-laser optical frequency standard based on trapped, laser-cooled, calcium atoms. Measurements of the intercombination line at 657 nm demonstrate linewidths as narrow as 400 Hz (line Q = 10^{12}), the natural linewidth for this transition. The fractional frequency stability of a laser locked to this resonance (in an unoptimized system) is already $5 \times 10^{-14}\tau^{-1/2}$, where τ is the averaging time. Ramsey fringes for typical operating conditions are shown in Fig. 3. The narrow linewidth of the transition along with the convenient wavelengths for probing and cooling (allowing use of diode lasers for interrogation and cooling) makes this an especially attractive optical-frequency standard.

The trapping and cooling light at 423 nm is generated by frequency doubling 846 nm light from a semiconductor master-oscillator power amplifier. This provides 50 mW of 423 nm light, which is used to cool and trap 10^7 atoms in 20 ms. A "shelving-detection" scheme, similar to that used for spectroscopy of trapped ions, has been used to interrogate the calcium line and stabilize the frequency of the 657 nm laser (fast linewidth of about 50 Hz). A phase-coherent, frequency-measurement chain for connecting this transition to the 282 nm transition of the mercury ion is now under development. (C. Oates).

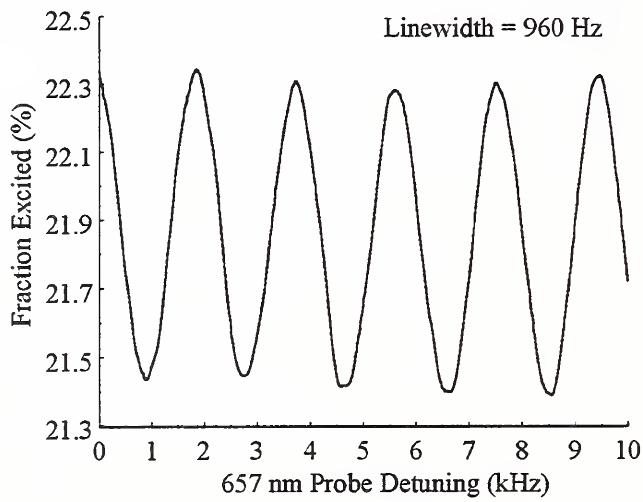


Figure 3. Ramsey fringes for the cold-calcium optical frequency standard.

■ Subsystems for Optical Frequency Measurements. Staff members of several Groups in the Division have developed laser-frequency measurement technologies for application to the construction of a frequency synthesis system capable of measuring optical frequencies with an accuracy limited by atomic frequency standards. The system will be used to interconnect and compare new optical-frequency standards such as the calcium and mercury-ion standards, and eventually to connect these references to the cesium primary frequency standard. The design concept involves three successive subdivisions of optical-frequency intervals plus one frequency doubling to arrive at a point at which ultrashort laser pulses can be used to measure the smallest frequency interval relative to the cesium primary standard. The ultrashort-pulse technique (developed at the Max Planck Institute) to be used in this last step involves a frequencies generated by a mode-locked, titanium-sapphire laser.

The larger steps of optical-frequency subdivision are achieved using mixing crystals of periodically poled lithium niobate. These crystals have been custom fabricated (in collaboration with staff of EEEL) to obtain efficient second-harmonic generation and sum/ difference frequency generation. With these devices a preliminary measurement was made of the mercury ion transition (532.360 800 THz) relative to the accurately known calcium transition at 657 nm. Further development of the system this year will provide an improved measurement of the mercury-ion transition relative to the calcium transition. Completion of the connection to the cesium standard is expected within approximately two years. (L. Hollberg and J. Bergquist)

■ **Direct Observations of Spatial Structure of Crystallized Ion Plasmas.** Large numbers of beryllium ions (up to 10^6 or more) can be stored in Penning traps by a combination of static electric and magnetic fields and laser-cooled temperatures so low that the ions freeze into a rigid lattice. Previously, Bragg scattering with the same laser light used to cool the ions was used to determine general features of the spatial structure. It was found that, for approximately spherical plasmas having 200,000 or more ions, the Bragg scattering pattern was consistent with a body-centered cubic (bcc) lattice, the theoretically predicted structure for the infinite-volume limit.

More recently, T. Mitchell, J. Bollinger, and W. Itano of the Division observed direct images of the ions fluorescing in large, spherical plasmas. These images showed the central regions of the plasmas to have bcc structure, or, more rarely, face-centered-cubic structure. In order to obtain these images, it was necessary to phase-lock the rotation of the plasma to an external electric field. The imaging camera could then be gated synchronously with the rotation, which has a frequency of about 1 MHz in this case. The ability to control the state of the plasma with this high a degree of accuracy would be of great importance to a frequency standard based on ions in a Penning trap.

Very flat, radially extended plasmas have been observed to have a structure like a stack of planes. As the density of the ions is increased, the plasma goes through a series of structures having square, rhombic, or hexagonal ordering within a plane. At certain values of the density, another plane is formed. The observed structures are in good agreement with calculations made by D.H.E. Dubin of the U. California, San Diego. (W. Itano)

■ **NIST-F1: A Cesium-Fountain Primary Frequency Standard.** Over the last half year, S. Jefferts, D. Meekhof, and D. Lee, along with F. Levi of the IEN in Italy, have brought NIST's new cesium-fountain frequency standard into operation, and they recently completed a preliminary evaluation of its uncertainty at a level commensurate with that of NIST-7 (5×10^{-15}). This evaluation was limited entirely by statistical noise (not systematic effects), since the stability of the standard is still more than an order of magnitude worse than we expected. A Ramsey pattern for the standard is shown in Fig. 4. The narrowest Ramsey fringe observed to date has a width of about 0.6 Hz. The magnetic field applied to separate the Zeeman lines is 0.1 μT, and the Ramsey fringes observed on the first Zeeman line indicate that the field along the flight path of the atoms is uniform to about 10 pT. This indicates that the magnetic shielding is quite good.

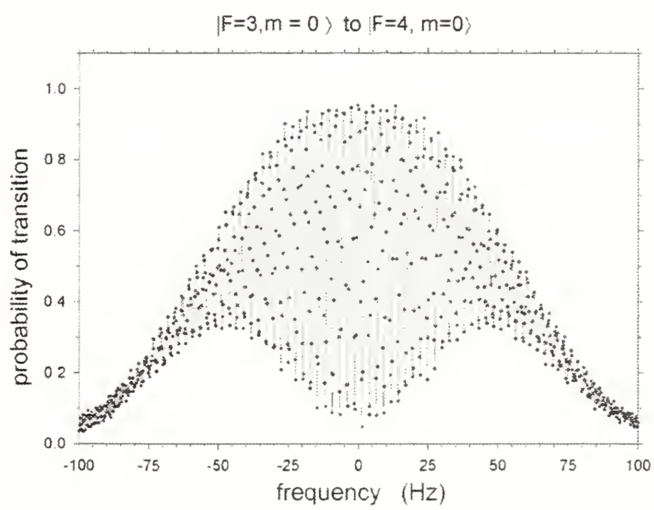


Figure 4. Ramsey fringes for the NIST cesium-fountain frequency standard. The dots show the actual data, while the lines simply connect data points in sequence, so the amplitude noise apparent in the envelope of the curve is not real.

This standard differs from other fountain standards in that the microwave cavity and atom drift tube are an integrated structure that serve as the vacuum chamber for the standard. This provides exceptional immunity to microwave leakage fields. For all other fountain standards, the microwave cavity and drift tube are contained within a vacuum chamber, and microwave leakage can cause difficulty. The laser system used to generate the multiple beams that cool, trap and launch the atoms involves a single master-oscillator power amplifier that provides sufficient power for all of the beams. Other fountain standards typically employ an array of independent diode lasers that are injection locked to a lower-power master oscillator. Future efforts on this project will focus on improving stability so that better evaluations can be made of systematic frequency shifts. (D. Meekhof and S. Jefferts)

■ **A Laser-Cooled Primary Frequency Standard in Space.** Several Groups within the Division, in collaboration with staff members of the Atomic Physics Division and a faculty member at the U. Colorado, are now engaged in a flight definition study for a laser-cooled-cesium clock in space. The project, called Primary Atomic Reference Clock in Space (PARCS), is aimed at an improved realization of the definition of the second, improved coordination of time/frequency standards on earth, and tests of several aspects of special and general relativity. The microgravity environment of space allows us to use slower atoms and increase interrogation time, thus improving clock performance. Assuming that the project can remain on an ambitious development schedule, flight should occur aboard the International Space Station (ISS) in 2003.

Figure 5 shows a schematic diagram of the proposed clock. The core of the clock (the physics package) is made up of: 1) the atom-preparation region where atoms are laser cooled, trapped, and launched; 2) a microwave cavity where atoms are subjected to microwave radiation at the cesium resonance frequency; and 3) a detection region where laser fluorescence is used to determine whether the microwaves have caused a transition. The objective is to achieve a stability of $3 \times 10^{-14}\tau^{-1/2}$ and an absolute uncertainty of 1×10^{-16}. (D. Sullivan)

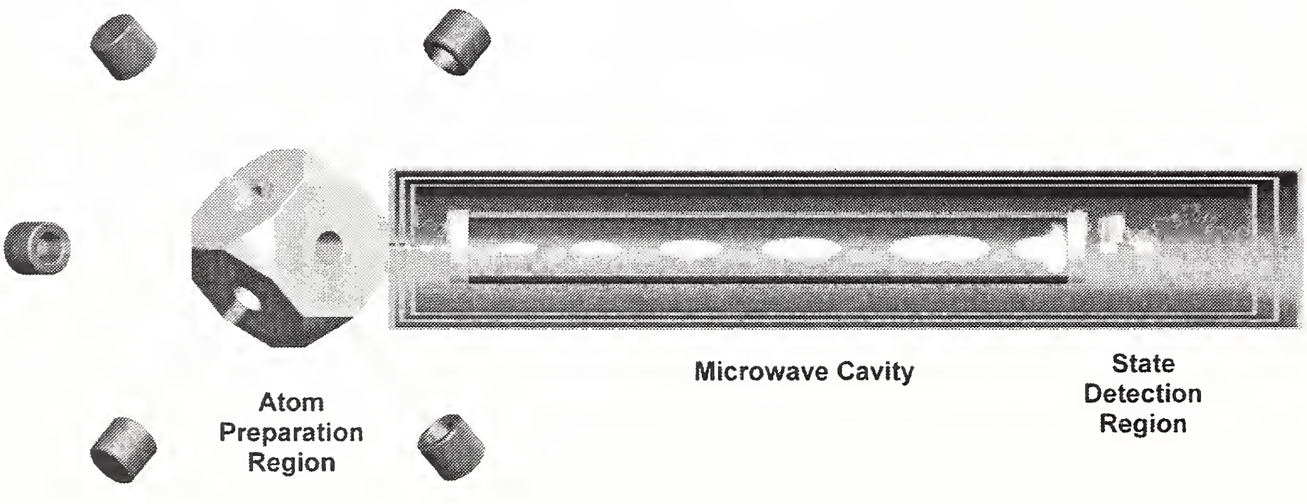


Figure 5. Diagram of the proposed space clock. Details of the microwave cavity have been omitted to more clearly show the expansion of the atom balls as they proceed through the cavity.

■ **Joint U.S.-Japan Development of a Frequency Standard**. A joint project between the Time and Frequency Division and the Communications Research Laboratory (CRL) in Japan to develop an improved version of NIST-7, the U.S. primary frequency standard, has recently been completed. The objectives of this project, funded by CRL, were to construct an optically pumped standard with an uncertainty comparable to that of NIST-7, to compare this new standard with NIST-7, and to improve a number of subsystems allowing for more-rapid, automated evaluation of systematic frequency offsets. B. Drullinger and D. Lee led the project, with major contributions from D. Jennings, L. Mullen, C. Nelson, J. Shirley and F. Walls. In addition, during the entire three-year course of development, at least one staff member from CRL was always engaged in the project.

The final comparisons between the new standard and NIST-7 indicate agreement within the nominal uncertainty (5×10^{-15}) of the two standards. Major improvements made during the project included a more robust diode-laser system for optical-state preparation and detection, new servo-control and monitor software using a more-flexible object-oriented approach, identification of a number of smaller sources of systematic offset, and improved modeling of several of the larger systematic frequency shifts. Improvements made to the new standard during this development project will now be incorporated in NIST-7. Aside from these improvements, the key benefit of this project was the demonstration of agreement between these independent standards. It would have been difficult for NIST to justify construction of a second standard for this purpose. (R. Drullinger)

■ Frequency Synthesizer for Laser-Cooled Atomic Clocks. F. Walls, with guest researchers A.S. Gupta and D. Popovic, has recently developed an improved microwave frequency synthesizer with a performance sufficient to support laser-cooled atomic clocks being developed as new primary frequency standards and for advanced space applications. This new synthesizer makes use of simple and rugged digital technology, some key components of which are already space qualified. The phase stability, temperature coefficient, and frequency agility should be more than adequate for every standard now under active development and might well serve generations of standards beyond these. It should also find application in standards for phase-noise and amplitude-noise measurements.

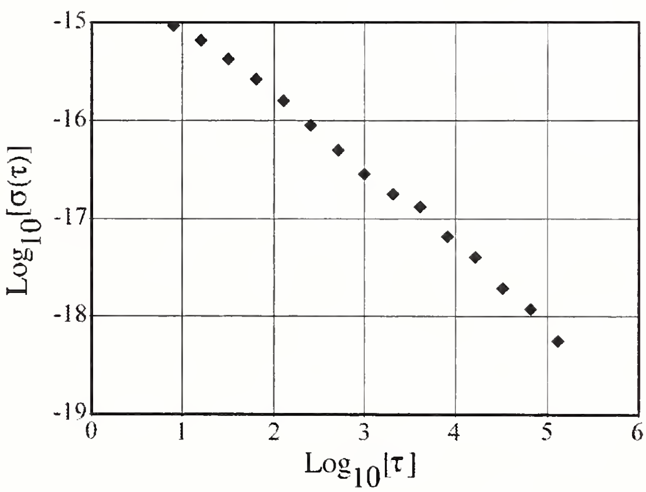


Figure 6. Measured fractional-frequency stability between two of the new microwave frequency synthesizers as a function of averaging time τ.

The key design advances have been the use of digital technology and the removal of narrow-band filters, which typically produce temperature-stability and phase-stability problems. Measurements between a pair of these synthesizers are shown in Fig. 6. For each of the pair of synthesizers, these data indicate a fractional-frequency stability of better than 7×10^{-16} at 10 s, averaging down to 1×10^{-18} at 1 day. The measured temperature coefficient is 0.12 ps/K. This synthesizer is small, and the circuitry is easier and less costly to assemble since there are many fewer critical adjustments involved. (F. Walls)

■ Improved Time-Scale Reference for Division Programs. T. Parker, F. Walls, and J. Levine have collaborated to improve both the performance of the NIST time scale and distribution of time-scale signals to key programs within the Division. Drift and noise in signal distribution to clock research laboratories and time-transfer stations have been reduced through installation of improved distribution amplifiers and much higher-quality coaxial cables. This has been needed particularly for studying and evaluating the new generation of laser-cooled frequency standards and for improving the reference used at satellite time comparison stations where the NIST time scale is compared with those of other world standards laboratories. The temperature coefficient of delay of the new cable is dramatically better than conventional cable, resulting in a more stable transmission delay despite the fact that the cable runs through areas that experience rather large temperature excursions.

The real-time output of the time scale is now generated by steering the output of a special synthesizer (driven by a good clock in the time scale) to the ensemble average of the clocks in the time scale. Of course, steering corrections to international UTC are also interjected into this system. The RMS error in this generation is now below 10 ps, an improvement of about a factor of 30. Finally, all five of the NIST masers are now contributing to the time scale. This has improved the time-scale stability to $\sigma_y(\tau) \cdot 3 \times 10^{-16}$ at $\tau = 5$ days. (T. Parker)

■ GPS Carrier-Phase Time Transfer. In collaborative work between J. Levine of the Division and K. Larson of the University of Colorado, GPS signals were used to achieve a time transfer resolution between Washington and Boulder of 100 ps for an averaging time of 1 day. The traditional approach to high-accuracy GPS time transfer involves two observers making observations of the same code-based timing signal from a satellite that can be viewed simultaneously by both. This approach is limited in resolution to 2 ns to 3 ns when averaging for 1 day.

The method employed in these experiments uses the phase of the GPS microwave carrier (rather than the code) for the common-view time transfer. This process involves identifying the same cycle of the carrier (or cycles of the carrier separated by a constant number of cycles). This is a substantial problem because the frequency is high, each satellite is in common-view for only a short period, and there is no reference available to help identify a particular cycle. The process employed is patterned after that used by geodesists, wherein the observations from a large number of other sites are compared and adjusted to obtain consistency and arrive at the appropriate cycle identification. They were able to achieve this for periods lasting many weeks.

This work is critical to the comparison of the frequency accuracy of new generations of laser-cooled, atomic frequency standards that are now being developed at laboratories around the world. The method should provide for an order-of-magnitude improvement in the precision of frequency comparison. This first experiment already allows frequency comparisons at a level of 1×10^{-15} over about 1 day. (J. Levine)

■ **GPS Common-View Timing Receiver with Multiple Channels.** J. Levine, V. Zhang, and A. Gifford have developed a Common-View Timing Receiver based on a commercially available, general-purpose, multi-channel GPS receiver. The system functionality is similar to that of earlier receivers developed at NIST except that the current receivers are much simpler and less expensive and track up to eight satellites simultaneously. One objective of this development was the replacement of older, NIST-developed receivers that have been used for many years for international time coordination. Many parts for these older receivers are no longer available, so maintenance is becoming progressively more difficult. Aside from Boulder, the new receivers are now located at the US Naval Observatory and the BIPM. Data from these receivers are automatically transmitted to NIST once each day.

The receivers are also being used in other applications. For example, data from one receiver located at NIST are downloaded every morning to a web site providing the means for achieving NIST traceability using GPS signals. These receivers are also being installed at a number of DOD sites where they will be used to achieve high-level synchronization for DOD programs. (J. Levine)

■ **Multipath Effects in Time Transfer.** Improved primary frequency standards and time scales have put increasing demands on the performance of international time comparisons using GPS common-view and two-way time transfer. In an effort to respond to this demand, F. Ascarrunz and T. Parker have been studying methods for improving the performance of Division time-transfer systems. Of particular significance is their development of an understanding of the impact of multipath signals on time transfer with pseudo-random-phase codes used with both two-way satellite time transfer and with common-view, GPS time transfer. Their analysis shows that multipath effects exacerbate the difference between the observed phase delay and the group delay. This understanding should allow improvement of two-way time transfer through more appropriate choice of the code chip rate. It focuses more attention on minimizing multipath effects in common-view time transfer, where it is not feasible to make chip-rate changes.

They have also developed a calibration system for two-way time transfer, providing a means for evaluating (and thus controlling) the delays through the entire satellite ground station. Improved cables have cut the delay variations in the calibration system from 200 ps to 50 ps. (T. Parker)

■ **Frequency Traceability to NIST Using GPS.** M. Lombardi and J. Levine have developed an on-line database of comparisons between the NIST time scale and the Global Positioning System (GPS) satellite signals. Calibration laboratories using GPS signals as a frequency reference can access the database to complete their chain of traceability to NIST. The database is automatically updated each morning and past data are archived. The archive allows users to retrieve past data and retroactively confirm the traceability of their measurements. This service was developed in response to requests from calibration and standards laboratories and from GPS receiver manufacturers who develop products for the time and frequency marketplace. (M. Lombardi).

■ **Year 2000 Time/Date Service.** The Time and Frequency Division has established a time server to assist users in testing the performance of time-setting software after the year 2000 (Y2K). The transmitted time of day is correct and is directly traceable to the NIST time scale, but the date portion of the message is exactly 2 years in the future. Access to the Y2K service is by telephone or through the Internet. All of the common digital time formats are supported.

The service, developed by J. Levine was inaugurated at the end of October 1998, and will stay in operation through the end of 1999. To facilitate using the Internet-based test system, NIST has also modified its client software to allow users to select either the normal servers or this special test system. This modified software is available on the Internet. (J. Levine)

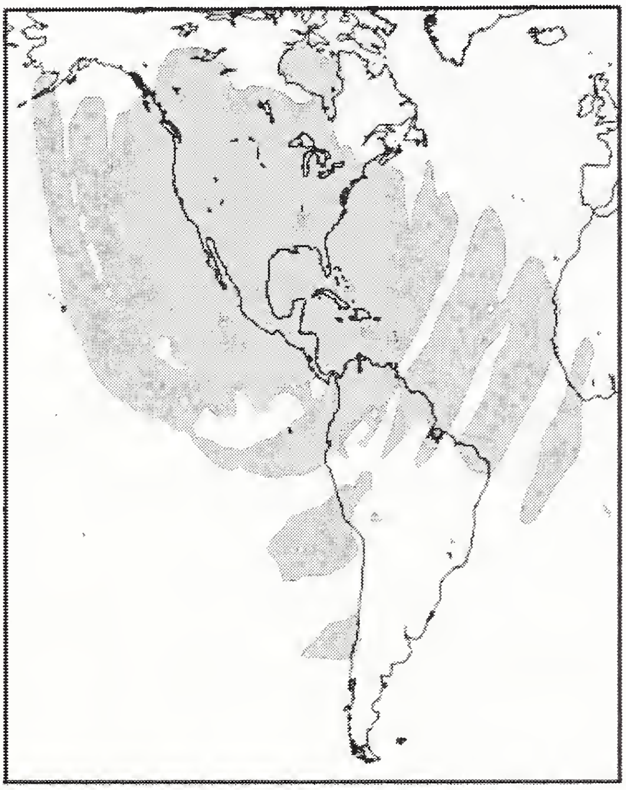


Figure 7. Electric-field-intensity contours (100 μV/m) projected for operation of WWVB at 50 kW radiated power during night-time hours. The nulls in the pattern are caused by interference of the ground wave and the sky (reflected)

■ **Completion of the Second Phase of Upgrade of WWVB.** Staff members at the NIST radio-station site north of Fort Collins, Colorado, working with staff members of the Time and Frequency Group, have completed the second phase of upgrade of WWVB. This phase of upgrade of the 60 kHz broadcast service involved development of a second, identical, transmitting system including a reconditioned low-frequency antenna and associated helix house, new transmission line, and high-power transmitter. The two transmitting systems, operated together in phase, will produce 50 kW of radiated power. This should be compared with the initial starting point of 10 kW and the most recent output of 23 kW achieved following completion of the first phase of the upgrade. In emergencies, one transmitting system can radiate the full 50 kW of power. However, this mode of operation reduces tube life significantly. Modifications of the WWVB building, now in progress, will allow the installation of a third transmitter to back up the present transmitters. At 50 kW of radiated power, the broadcasts will more completely cover the continental United States as shown by the modeled, field-intensity contour in Fig. 7. This should allow for commercial development of a broader range of simple clocks and frequency standards based on these broadcast signals. (W. Hanson).

■ **Lasers for Wavelength-Scanned Interferometry.** R. Fox and L. Hollberg of the Division have been collaborating with L. Howard and J. Stone of the Precision Engineering Division of MEL on the development of rapidly scanned diode lasers for application to wavelength-scanned interferometry. This is a length-measurement process that does not require physical movement of the arm of an interferometer. The requirements for the laser system are that it must operate with a single longitudinal and transverse mode, and that its wavelength (oscillation frequency) can be scanned continuously and rapidly without mode jumps. After some study of several laser types, a distributed-Bragg-reflector laser with a three-electrode structure was selected for testing. The 852 nm laser and optics have been enclosed in a "hand-held," 40×40×100 mm package (see Fig. 8).

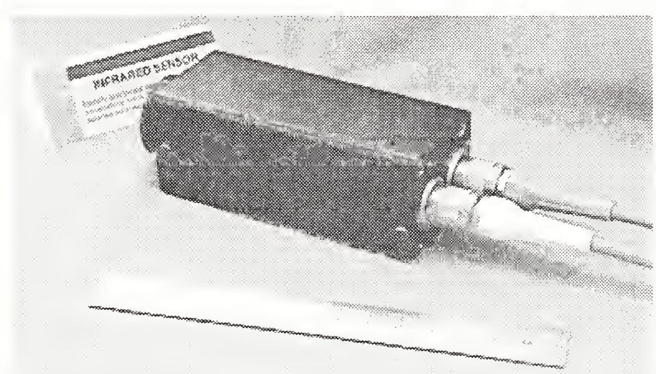


Figure 8. Photograph of the new diode-laser source for wavelength-scanned interferometry

A tuning range as broad as 1.3 nm at 852 nm was demonstrated, with the period for tuning through the full range being as short as a few ms. The modular electronic systems used to power and control the laser are of a standard design that could be substantially miniaturized if necessary. Staff members of the Precision Engineering Division are now testing the system. The objective of this joint project is to achieve precision length metrology with systems that can be easily used in a machine-shop environment. (R. Fox).

Optical Gain Without Population Inversion. In recent experiments conducted by J. Kitching and L. Hollberg, optical gain without population inversion (GWI) was observed in a sample of laser-cooled, trapped atoms. This gain results from quantum interference arising from coherences established in the atom by the applied optical fields. Interpretation of results on GWI and lasing without population inversion (LWI) has involved substantial controversy, and this experimental work stands out as particularly unambiguous in interpretation. In the experiments, ^{87}Rb atoms were laser cooled and trapped in a magneto-optical trap (MOT). The observed gain was as much as 0.2% per pass through the trapped atoms at a wavelength of 795 nm in the presence of a strong drive laser at 780 nm. Direct measurements established that there was no population inversion between the relevant excited and ground states. Other measurements were made to rule out any explanation based on direct Raman processes. The results indicate promise for the use of optical coherences in generating shorter wavelength radiation. (L. Hollberg)

Compact Rubidium Oscillator. L. Hollberg and F. Walls, with guest researchers N. Vukievi and A. Zibrov, have developed a new frequency reference based on Raman transitions in rubidium. The objective is a frequency reference that is very compact, portable, and low-power. While several different modes of operation have been studied, the most promising involves the 3 GHz transition in ^{85}Rb, where resonance linewidths as narrow as 800 Hz have been observed. This is an attractive transition because it permits the use of commercially available low-power electronics. The observed stability of a table-top prototype device, even in this embryonic stage of development, is $< 1 \times 10^{-10}$ between 1 s and 1000 s. Further development should result in a much better stability. With some engineering effort, the size of the device could be reduced to about $3 \times 3 \times 9$ cm^3 and the power consumption reduced to the order of 1 W. Studies of longer-term stability and environmental sensitivity are now underway. This oscillator has potential applications for electronic instrumentation, telecommunications, and aerospace systems. (L. Hollberg)

Nitrous-Oxide Frequency Standards. In measurements performed by K. Evenson and guest researchers T. Varberg and F. Stroh, substantial improvements have been made in the frequency uncertainties of more than 200 spectral lines of ^{14}NO and ^{15}NO covering the spectral range from about 200 GHz to 5 THz. Uncertainties for all of the measurements were 10 kHz or less. The measurements were made using tunable-far-infrared spectroscopy, wherein a tunable microwave signal is mixed with CO_2 difference frequencies to produce probe radiation covering the desired spectral region. These laboratory measurements are needed for study of the ozone chemistry of the upper atmosphere and for calibration of Fourier-transform spectrometers. (K. Evenson).

Study of Bending Transitions in the Far Infrared. M. Allen and K.M. Evenson have collaborated with guest researcher H. Körsgen on the first high-resolution measurements of bending transitions in the far-infrared region of the spectrum. Laser-magnetic-resonance (LMR) spectroscopy was used to study these transitions in FeD_2, CCN, HCCN and DCCN in the vicinity of 6 THz. The measurements were made possible by substantial improvements in the low-frequency output of the CO_2-pumped methanol laser. Aside from providing accurate frequency references for radio astronomy searches for these molecules in the interstellar medium, the results should allow exacting tests of molecular theory for these molecules. (K. Evenson)

NIST Time Web Site Lauded for Educational Impact. The Time and Frequency Division's web site entitled "A Walk Through Time" was selected by the Tech Museum of Innovation as "one of the ten best technology web sites we've found for middle-school and above students, teachers, and parents" for the month of June, 1998. The "Tech Ten" award is presented to web sites that bring the best in technology education to middle-school and above audiences. To receive the award, web sites must be "focused on high technology and innovation; be relevant and understandable to a middle-school audience; and be fun and engaging."

San Jose's Tech Museum of Innovation, in the heart of Silicon Valley, is a hands-on technology museum "devoted to inspiring the innovator in everyone." In citing the Time and Frequency web site, the museum noted "this history of time and measurement is anything but dry. Explore the mysteries of Stonehenge, or the calendars of ancient Babylon, all the way up through today's atomic clocks and satellite-broadcast time services. Time definitely doesn't stand still here." (J. Wessels)

FUTURE DIRECTIONS

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

■ **Telecommunications Networks**. The Division has had strong interactions with the telecommunications industry on a number of synchronization issues. This industry is going through a period of rapid development and change where measurements and standards can play a positive, organizing role. The Division is in an excellent position to contribute to the development of improved synchronization strategies as well as to support the industry with methods for characterizing the performance of synchronization components and systems.

■ **Time Series Analysis**. Over the last two decades, the Division has been a leader in the development of statistical methods for time-series of clock and oscillator data. For such timing systems, the standard deviation does not always yield correct results, particularly where the behavior of systems is observed over long periods (as is done with standards) where assumptions about noise properties are usually incorrect. To take better advantage of time-series-analysis methods requires further developments, especially in the analysis of unequally spaced data. Furthermore, the ideas must be simplified if they are to be widely used. Additional work is also needed on cross-correlation methods and the modified Allan variance, and new measures are needed to more adequately specify the occurrence of large excursions from the mean. Such measures are important in areas like telecommunications where average behavior is less important than short-period, large excursions that lead to lost packets of information.

■ **Satellite Timing**. One of the key limitations to satellite time transfer is the uncertainty in signal propagation time ariseing from variations in the index of refraction of the troposphere and in the electron density of the ionosphere. The Division has 1) completed preliminary tests on a system for doing time transfer using the phase of the GPS carrier; 2) developed a two-frequency receiver for determining ionospheric delay from GPS satellites and 3) completed and successfully field tested a three-wavelength geodimeter for accurate terrestrial length measurements in air. Expertise developed through these diverse projects can be used to improve the performance of time and frequency comparisons made using satellite systems.

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

- Quantum-limited measurements on atoms. The ability to detect atomic states in individual atoms or ions with nearly100% efficiency enables studies of the fundamental limits of quantum noise in measurements. Theoretical studies show that, with the use of certain quantum mechanically correlated states, the time required to reach a certain measurement precision can be reduced by a factor equal to the number of ions in the sample. Experiments are underway to prepare such states.
- Quantum computation. The first demonstration of logic gates using quantum bits (superpositions of 0's and 1's) have been demonstrated using trapped atomic ions. Current efforts are devoted to increasing the number of bits in a register to perform calculations and create correlated states.
- Creation and quantum-state tomography of nonclassical states of motion. Coherent, squeezed, Fock, and "Schrödinger cat" states of motion have been created in the motion of trapped atomic ions. This problem has a formal connection to and provides an interesting complement to studies of cavity-QED.
- Study of Influence of Radiation Fields on Atoms. Here we compare predictions of quan-

tum and semi-classical theory and study radiation damping and frequency pulling in cavities.

- High-Resolution Optical Probing of Cold, Trapped Neutral Atoms. Such experiments are needed to guide the development of future neutral-atom frequency standards.
- Improved Measurements of Atomic Fine-Structure Frequencies. These weak magnetic-dipole transitions can be directly measured using laser-magnetic-resonance methods.

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

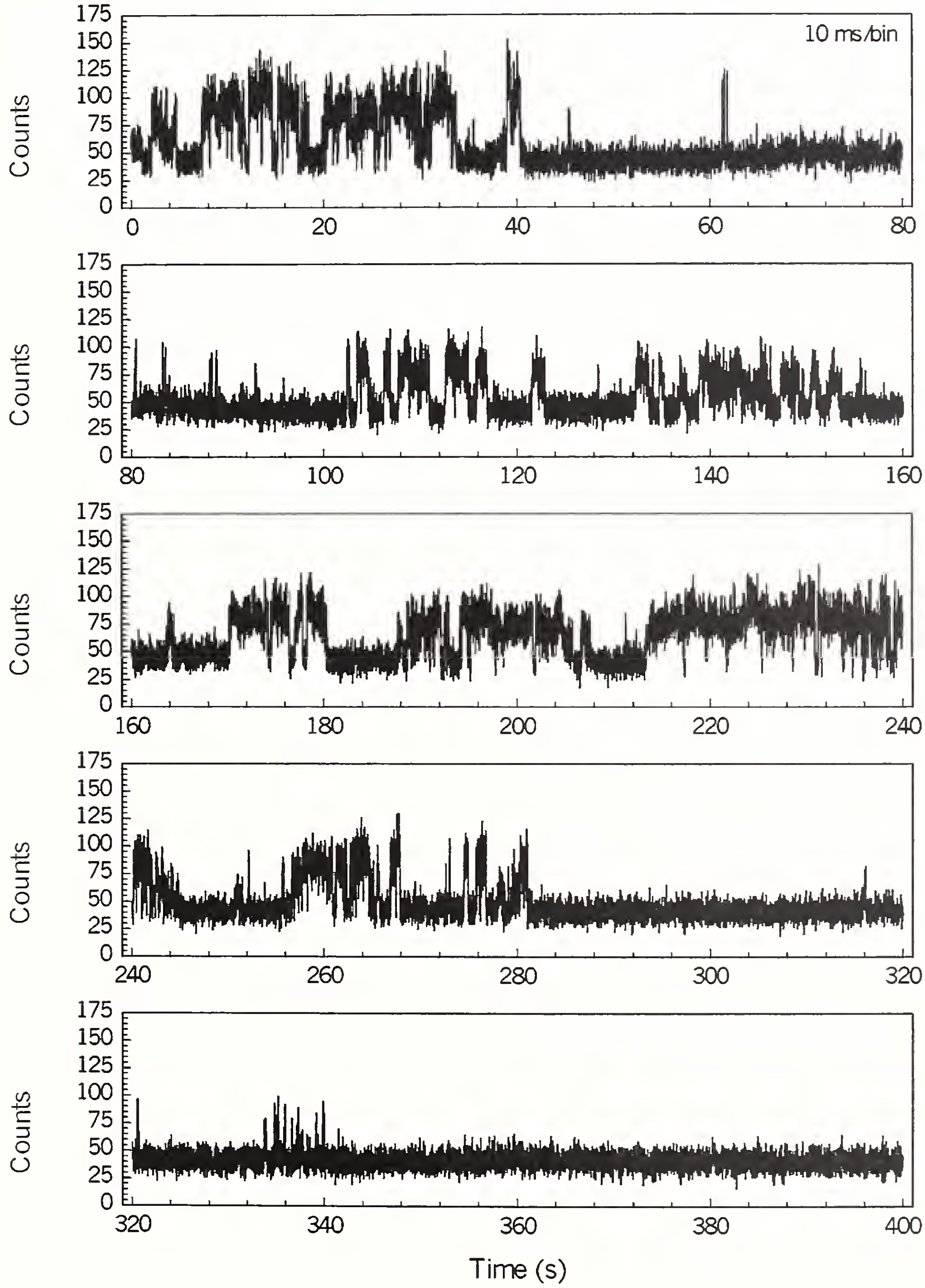
■ **Optical Physics.** Studies in optical physics revolve around the need to develop very narrow-linewidth sources of radiation at a variety of frequencies (from the microwave to the visible) and to accurately measure optical frequencies. Laser studies, including studies of fundamental noise processes,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

The Division is studying various approaches to measuring optical frequencies involving frequency multiplication and division. Of particular note is the development of custom-fabricated, nonlinear mixers using periodically poled lithium niobate (PPLN) for generating harmonics and sum and difference frequencies in important spectral regions. Combined with diode lasers and other solid-state lasers, these mixers offer unique opportunity for developing a synthesis chain linking the optical region to the cesium frequency standard.

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

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

QUANTUM PHYSICS DIVISION



Overleaf

Fluorescence Trajectory of a Single 30 Angstrom Radius CdSe Quantum Dot. The quantum dot exhibits a digital "on/off" emissive behavior as illustrated in five panels covering a total of 400 seconds. Periods of emission are followed by dark periods where it no longer emits light.

QUANTUM PHYSICS DIVISION

MISSION

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

- develops the laser as a precise measurement tool;
- determines fundamental constants and tests of the fundamental postulates of physics;
- exploits Bose-Einstein condensation for metrology and low temperature physics;
- devises new ways to direct and control atoms and molecules;
- characterizes chemical processes and their interactions with nanostructures.

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

ORGANIZATION

The 21 permanent senior scientists ("Fellows") of JILA form a governing body that sets policy, subject to review by the Director of NIST and the President of CU. A biennially elected Chair, assisted by an executive committee, is responsible for operating the Institute within the policies set out by the Fellows. Of the present 21 active Fellows, four are tenured, State of Colorado faculty members in the Department of Physics, two in Chemistry, and eight in Astrophysical and Planetary Sciences. Seven are NIST employees, six in the Quantum Physics Division and one in the Time and Frequency Division. Currently, one additional CU scientist and two NIST scientists are "Associate Fellows." All of these scientists work side by side, sharing facilities and responsibility for the success of the Institute, yet each remains officially responsible to the respective employer, NIST and the Physics Laboratory Director in one case, CU and the pertinent academic department in the other. At the present time, approximately 60 graduate students and postdoctorals are being supervised by NIST scientists and approximately 35 staff are associated with NIST activities.

A direct outgrowth of the national space program in the early 1960's, JILA was formed in response to perceived serious gaps in our basic understanding and training in the physics of gaseous atmospheres (terrestrial, planetary, solar and stellar). JILA has evolved, responding to changing national needs and to the requirements of its parent organizations. It has become a world leader not only in atomic and molecular science, but also in precision measurement (including gravity, frequency standards, and geophysics), laser and optical physics, chemical physics, and astrophysics. Most recently it has expanded into programs involving surfaces and materials. As NIST's mission has changed to emphasize support for industry, so has the criteria with which division scientists have chosen to direct their research programs, as is indicated in the technical activities below.

CURRENT DIRECTIONS

■ **Laser Research.** In laser research, various schemes are explored for stabilizing the laser and also to use lasers as a possible (optical) frequency standard. Recent work addresses the creation and use of "ultrafast" laser pulses for investigating semiconductor materials, producing and controlling wave packets, and studying nonlinear optical wave interactions. Also, the evanescent wave property of light has been exploited to "guide" atoms (keep them from touching the sides) through hollow fibers.

■ **Fundamental Constants and Tests of Fundamental Postulates**. Here there is considerable overlap with the work in developing lasers as optical frequency standards as well in the efforts to produce different and better stabilized lasers. In addition, a new determination of *G*, the Newtonian constant of gravitation, has been made -- the value of which has been called into question by some recent experiments. At present, *G* is not connected to any of the other fundamental constants by any accepted theories; nevertheless, as one of the fundamental constants it provides a continuing challenge to precision measurement techniques. Work is progressing on making the transfer standard *g*, the acceleration of gravity, both more accessible to the external research community and more usable. Progress continues to be made in developing a six-degree-of-freedom, actively controlled, mechanical isolation system for a needed stable test bed for carrying out a number of precision measurements to test fundamental laws of physics. The isolation system will also facilitate the detection and study of gravitational radiation in the frequency regions between 100 and 3 Hz.

■ **Bose-Einstein**. Building on our lead position in Bose-Einstein condensation research investigations are being made on the various properties of these condensates. These include quantitative measurements of the basic thermodynamics and energetics of condensates and their response to standing-wave density fluctuations (or sound waves) in the condensates. The properties of two different but simultaneously existing condensates are studied in the same trap to improve the understanding of interacting condensates. The possible standards and precision measurement implications of these macroscopic quantum mechanical systems are also of great interest. Finally, and very important for a variety of applications, the coherence (laser-like) properties of these condensates are being studied.

■ **Control of Atoms and Molecules**. The Division exploits novel control mechanisms with optical light fields for a variety of advanced technologies utilizing the coherence properties of lasers. Novel wave packet states are produced with amplitude and phase control. Such results are important for the encoding of information in such fields as quantum computation. The control of cold atoms guided through hollow optical fibers offers promise for new kinds of atom interferometers and matter gyroscopes.

■ **Nanostructure Development**. Various forms of surface microscopies and optical probe techniques are important subjects for film-thickness control and the investigations of nanostructures. Through the competence project on near-field microscopy, challenges are being addressed for ultrafast time contrast and high spatial resolution, with some preliminary success. Deposition of films with precise layer thicknesses and composition are studied by laser detection methods and ion-scattering probes.

TECHNICAL HIGHLIGHTS

■ **Four Vector Correlations in Collisions.** The formalism and experiments for a four vector correlation, collisional process have been achieved for the first time. In an atomic beam of calcium atoms, two atoms are excited with a laser, which aligns the directions of the atomic orbitals, defining two vectors. A collision in a beam defines a third vector from the relative velocity, and the fourth vector is determined by the final state alignment after a collisional energy transfer process. Up until now, there have been only brief hints of such four vector correlations in other studies, but never actual measurements of cross section values. In this study, the complete formalism to extract four-vector correlation cross sections has been developed and experiments performed to obtain a large number of the cross section values for the first time. The experiments are performed on the system of two excited Ca atoms colliding to form one higher excited state and one ground state atom. There are 27 formal cross sections for the four vector process, and relative values for 18 of these have been obtained in the measurements here. (S.R. Leone)

■ **Surfactant-Controlled Nanodot Growth.** Nanoscale semiconductor devices present numerous possibilities for future studies of quantum confinement and single electron devices. The growth of germanium on silicon is a classic system in which nanodot growth occurs spontaneously because of the mismatch in lattice spacings. Typically a few layers of germanium will grow first, layer by layer, and then islands of germanium form to produce nanodots of varying sizes. In recent experiments, control of the size of the nanodots has been demonstrated by use of an arsenic "surfactant" during molecular beam epitaxy deposition of germanium on Si (100). Experiments are performed with controlled molecular beam epitaxy of germanium on silicon, with varying amounts of arsenic surfactant deposited first on the surface. Atomic force microscopy is used to investigate the island size after growth. Laser ionization mass spectrometry and reflection high-energy electron diffraction are used to correlate the desorbing fluxes of arsenic dimers and tetramers with the onset of island growth. The results show a dramatic alteration of the island size and density with application of modest amounts of arsenic surfactant in the range of 0.25-1.0 monolayers. (S.R. Leone)

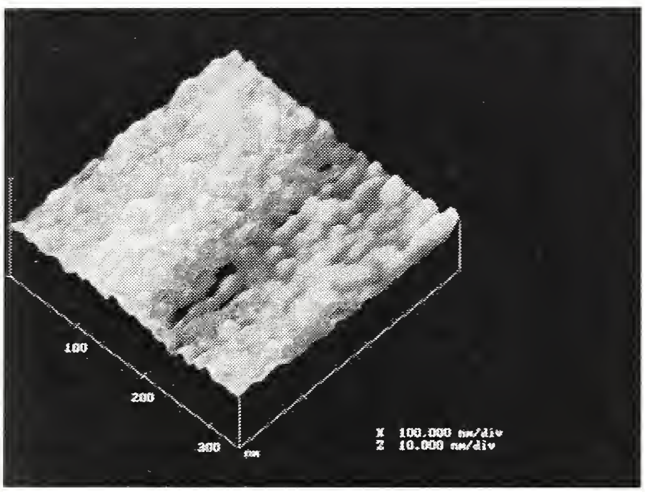


Figure 1. Germanium islands grown on Si(100) using arsenic as a surfactant.

■ **Infrared Near Field Optical Microscopy.** A new, infrared, near field, optical microscope has been constructed and used successfully to interrogate photoresist polymer films with wavelength tunability. The results show great promise for probing with molecular group specificity in various materials. A new method has been devised to pull small diameter fiber tips in infrared-transparent fibers. This method uses a two-step laser heating and pulling technique, so that the fiber is first pulled bluntly to an intermediate diameter and then pulled to a very small diameter tip to form the probe. The fiber is a zirconium-aluminum fluoride material, which can be successfully coated with metal to form the transparent waveguide tip. A three micron, tunable, color center laser is transmitted through the fiber with an efficiency of one part in 10000, and the improvement in spatial resolution is over a factor of six better than the diffraction limit of the light at these infrared wavelengths. (S.R. Leone)

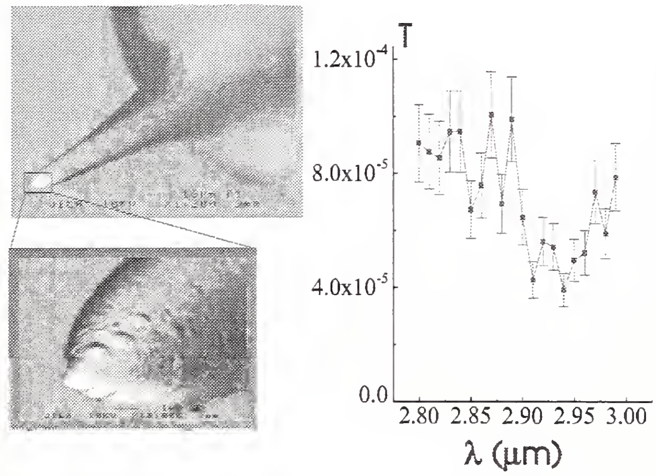


Figure 2. Fiber tips for infrared near-field microscopy. A new, two-step method, for pulling fluoride fibers leads to 200 nm tips (left) with enhanced infrared transmissivity (right).

■ **Optical Frequency Comb Generator -- Optical Frequency Shifter.** There have been considerable efforts toward converting the Optical Frequency Comb Generator into a versatile and dependable laboratory tool. The first version had several weaknesses, mainly optical inefficiency and the sensitivity of cavity tuning and alignment to temperature. The PID temperature controllers on both the crystal modulator case and on the optical mounting plate substantially eliminated these thermal problems. The optical inefficiency arose because of the high frequency-conversion efficiency of the 10.6 Ghz phase modulator: for a coherent optical input frequency, something like 1/3 of the power is "lost" by scattering to another sideband frequency. The cure is to add another mirror in the input line, also of ~99% reflectivity, and form an auxiliary Fabry-Perot cavity with the nominal Input Mirror. With PZT control, this auxiliary cavity can be locked on a transmission fringe for the input laser frequency, leading to a resonant transmission above 50%. The resulting apparatus has the new and elegant property that an input cw laser field is "transmitted" with an efficiency of ~10%, but with a controllable frequency shift of up to about 2 THz, in ~10 GHz steps controllable with rf precision. The optical spectral purity of the output beam is good, containing only about -20 dB of the strongest non-selected (neighbor) component. (J.L. Hall).

■ **Optical Frequency Measurement of I_2-Stabilized Nd:YAG Laser at 532 nm.** A major effort of the Physics Laboratory is to bring the frequency measurement chain "on-line." Our scheme is based on the accidental, numerical fact that 632 nm is half-way between the new I_2 standard of interest at 532 nm, and a known reference line at 778 nm based on the two-photon transition in Rb. In turn, this 632 nm point, provided by a stabilized diode laser in our system, is just 660 GHz away from the conventional, standard I_2/HeNe laser at 633 nm. One can observe a S/N above 30 dB (in 1 MHz bandwidth) on this red laser beat when the Optical Frequency Comb/Shifter is working well. The uv beat at 316 nm, which defines the 632 nm laser, is the comparison of the doubled diode laser frequency output (obtained with non-critical, phase-matched RDP) beating with the ~50 nW of sum frequency generated in angle-matched RDP. The uv beat S/N is usually in the range 15-20 dB in 1 MHz bandwidth. To provide accurate, phase-coherent operation of the frequency chain, these beat signals are tracked by phase-locking a VCO onto the coherent beat. This locking technology can work well: the proof of this statement is that measured frequency deviations correspond to >6×10^{-12} at 1 s, which is the noise level of the HeNe/I_2 reference laser. (J.L. Hall)

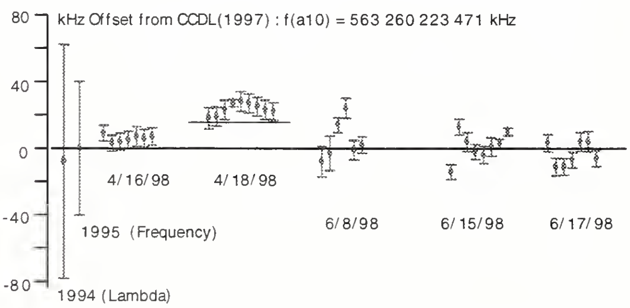


Figure 3. Apparent measured frequency of the a_{10} component of R(56) at 532 nm. The data of 4/18/98 are shown with their own baseline. June measurements were made to see limits of offsets caused by pre-filter mistuning, maladjustment of tracking filter gains, etc. Corrections for rf standard frequency and 633 nm I_2-stabilized laser offsets are not yet applied.

■ **NICE OHMS Spectroscopy, and Lasers Stabilized to HCCD and Iodine.** It has been interesting to compare lasers stabilized onto iodine resonances using modulation transfer method with lasers stabilized to HCCD resonances using the Noise-Immune, Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy (NICE-OHMS) method. (See Fig. 4) The HCCD-stabilized system shows only 2 to 4 times more short-term noise than the I_2 system, a remarkable success considering the green I_2 transition strength is half a million times stronger than the P(5) line of the C_2HD ($\upsilon_2 + 3\,\upsilon_3$) overtone band. The fact that amazing frequency stability is being achieved with such an extremely weak reference transition is a direct result of the spectrometer's ultra-high detection sensitivity. For concreteness we show the frequency stability achieved with the two approaches.

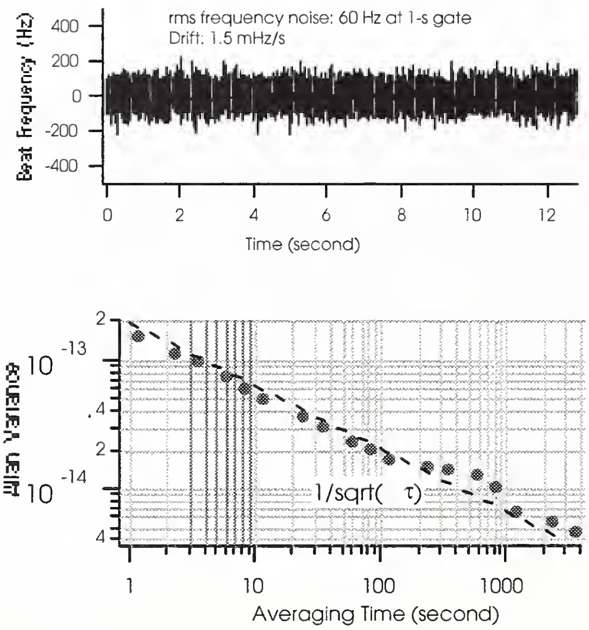


Figure 4. (top) Stability of beat between I_2 stabilized and HCCD-stabilized lasers. The improving ultrasensitive detection of a weak overtone resonance of molecular HCCD permits progressively better results on the laser stabilization. (bottom) The heterodyne reference laser is stabilized on an I_2 transition at 532 nm using modulation transfer spectroscopy. This reference laser has a stability ~5×10^{-14} at 1 s, from beating experiments with two I_2-stabilized systems.

The NICE-OHMS spectrometer naturally provides laser frequency discrimination information from both the cavity resonance and the molecular transition. Thus, it is an ideal system for simultaneously achieving good short- and long-term frequency stabilization. The laser frequency basically tracks the cavity resonance with a precision of a few mHz with a fast servo loop. The vibration noise and the long-term drift of the cavity can be eliminated by stabilizing to the intracavity molecular transition. (J.L. Hall)

■ **Apertureless Near Field Scanning Optical Microscopy.** With the ever-decreasing scale of electronic components and chip design, there is an ever-increasing need to develop efficient optical methods to measure properties of nanoscale objects with sizes well below the diffraction limit of light. There have been considerable breakthroughs in this area based on near field scanning optical microscopy (NSOM), which has conventionally been achieved by using metal coated, optical fiber tips to confine the light in rapidly tapered, optical fibers. However, this method is inherently limited by the skin depth of light in the metal cladding (≈12 nm for Al), which, even for optimum cases, yields only 20 to 30 nm resolution and, under typical operating conditions, more on the order of 100 nm resolution. An alternative, actively explored in the Nesbitt and Gallagher groups, is to develop new methods in *apertureless* near field scanning optical microscopy, which already have demonstrated resolution improvements down to the 2 to 3 nm length scale. This effort is based on a combination of: i) evanescent wave excitation of molecules/nanostructures on a prism surface; ii) sharp Si or Ag coated Si structures guided by atomic force microscopy (AFM) to condense the evanescent electric fields in the vicinity of the tip; and iii) resonant light scattering or fluorescence detection of the molecules/nanostructures subsequent to the excitation event. This method has been used to image Au nanospheres by resonant scattering of 543 nm light near the Au plasmon resonance, and to determine that the combination of AFM tip + particle leads to a scattering *enhancement* of over 4000-fold from that of the bare Au nanospheres. (D.J. Nesbitt and A. Gallagher).

■ **Fluorescence Based Near Field Imaging Methods.** We have been extending near field imaging methods into the fluorescence domain, where the Si and Ag coated AFM tips are used to influence the near field excitation of dye molecules doped in latex nanospheres. The resulting fluorescence is imaged with a high numerical aperture microscope and fiber coupled avalanche photodiode combination. What is observed is considerable spatial structure in the fluorescence NSOM images as a function of tip-molecule distance, indicating both enhancement as well as quenching effects due to the presence of the tip. Especially interesting in the NSOM images are the effects due to the AFM probe tip blocking the molecular fluorescence, which therefore represents the casting of a vastly sub-diffraction-limited "shadow" of a near field light source by a nanoscale object. These measurements represent a world record for the highest spatial resolution achieved to date with near field excitation and fluorescence detection. The results provide unprecedented, experimental benchmarks for comparison with near field theory, as well as a completely new method of near field optical imaging by spatially shadowing specific fluorescent sites on the nm length scale. (D.J. Nesbitt and A. Gallagher)

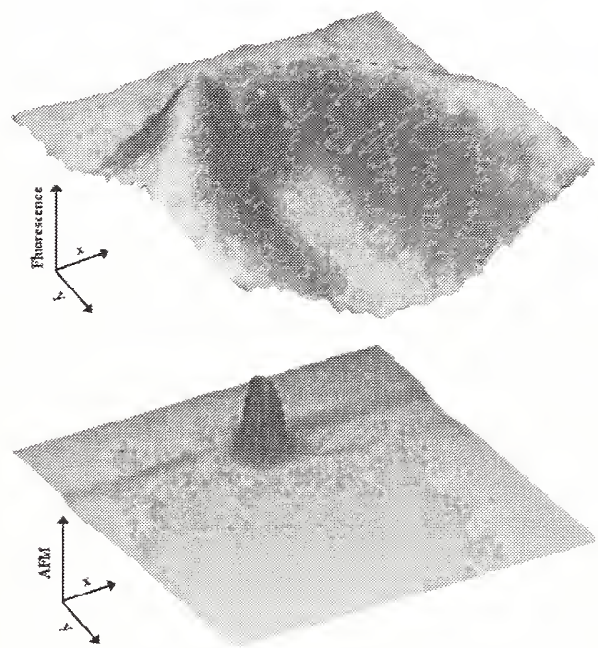


Figure 5. Apertureless AFM/NSOM fluorescence image of a dye doped polystyrene nanosphere (~80 nm) with the corresponding atomic force image below.

■ **State-to-State Reaction Dynamics in Crossed Molecular Beams.** Chemistry is a discipline of enormous technological and economic importance and yet a detailed understanding of how the simplest of chemical reactions occur still represents a state-of-the-art area of experimental and theoretical chemical physics research. There has been major progress in this area by exploiting slit discharges as an intense source of jet cooled F atoms for state-to-state reactive scattering studies in crossed supersonic jets. As the initial target, the focus has been on the classic $F + H_2 \rightarrow HF(v,J) + H$ reaction, where the nascent rovibrational product states of HF are detected via direct IR laser absorption methods. The powerful advantage of such a high resolution, laser based approach is that it offers 10^{-4} cm^{-1} spectral resolution on the product states, which is 5 to 6 orders of magnitude better than previous crossed beam time of flight studies. These studies have yielded for the first time, collision free, fully quantum state resolved, product state HF (v,J) distributions from the F + H_2 reaction. These can now be studied as a function of center of mass collision energy. The experimentally observed distributions are in good qualitative agreement with state-of-the art *ab initio*/dynamics calculations. The data also reveal significant discrepancies between theory and experiment, providing the first experimental evidence that multiple electronic potential surfaces (i.e., with both ground state, spin orbit excited F atoms) are involved in the reaction event. This evidence for the importance of *non-adiabatic* processes in this simplest of "benchmark" systems implies a much richer range of dynamics for chemical reaction systems than heretofore suspected. (D.J. Nesbitt).

■ **Second Harmonic Generation from Si(100)/SiO_2.** The Si(100)/SiO_2 interface is critical to the semiconductor industry. The channel region in a MOSFET is Si(100), while the gate dielectric consists of SiO_2. The thickness of the gate dielectric must scale in proportion to the scaling of the channel length. The current generation of integrated circuits has oxide thickness of approximately 9 nm, but within 2 to 3 generations the thickness will shrink to 4 nm. The necessity for extremely thin oxides has made roughness at the Si/SiO_2 interface a topic of increasing importance in the industry.

Optical second harmonic generation has been shown to be sensitive to roughness at this interface. In materials with bulk inversion symmetry, second harmonic generation is only dipole allowed at an interface or surface, making it a highly interface/surface selective technique. However, the underlying physics that gives rise to the roughness sensitivity is not understood. We are investigating why second harmonic generation is sensitive to roughness. Our experiments are focused on measuring the spectral dependence of the signal. There are resonant structures that can be attributed to various features in the band structure of silicon.

The preliminary results indicate a previously unknown resonance in the second harmonic spectrum. It is manifest as a strong increase in the signal at the blue end of the spectral region that the incident laser can tune over. Most strikingly, this resonance shows different symmetry properties than adjacent spectral regimes. The symmetry properties suggest that the signal is arising from step edges at the interface. If confirmed, this would be a very interesting result because we will have identified interface features that influence the second harmonic spectrum. Efforts are underway to extend the tuning range of the incident pulses using an optical parametric oscillator. This will necessitate the use of a reference signal to allow comparison of results from the optical parametric oscillator and laser. (S.T. Cundiff)

■ **Isolation System**. New, more sensitive seismometers with interferometric readouts have improved the performance of our low-frequency, active isolation system. The low-frequency, active isolation system comprises multiple, suspended stages with six seismometers on each to sense the diminished disturbances that penetrate the passive suspensions. Control systems cause actuators to counter the residual disturbances on each stage. The "preliminary" stage, which operates outside of vacuum, has optical imaging readouts of its seismometers. It is fully operational and meets its design performance goals of a factor 100 isolation down to 1 Hz. The two "main" stages are housed in a vacuum system that is supported by the preliminary stage and has seismometers with both low sensitivity, imaging readouts for quieting and high sensitivity, interferometric readouts for maximum disturbance reduction. The first main stage now has operating interferometers on all six seismometers. The second main stage has not been instrumented with seismometers, but has a complete suspension and dummy payload. We have demonstrated 70 dB of isolation in vertical and horizontal degrees of freedom with both the preliminary and the first main stage control loops active. This demonstrates that such stages can be stacked, that they are stable in a stacked configuration and that high gains are simultaneously achievable on both stages. The demands on seismometer sensitivity increase at each inner stage because the remaining disturbances are reduced by another outer stage. Research continues on seismometer improvements and technical challenges stemming from the intricate control systems. (J.E. Faller)

■ **New, Small, Absolute, and Highly Portable Gravity Instrument.** Work is progressing extremely well in the development of a new, mechanical, cam-based, free-fall (i.e., dropping) system. This is to be integrated in a small, fast, portable, and simple-to-use absolute g instrument. A two-centimeter free-fall drop is created by using a rotating cam to drive the dropping chamber. This approach results in a high measurement rate of 3 drops per second. The feasibility of this approach has been demonstrated, and presently a refined and evacuable apparatus is under construction. At the same time, and in the interest of both simplicity and instrumental cost, an alternate, passive spring system is being worked on as a possible replacement for the traditionally used "super spring." During the last year a major conceptual breakthrough occurred in regard to this development. By employing a double cam with the second half of the cam driving an auxiliary mass, the center of mass of the instrument does not move. Thus its motion can be used to cancel out ground-sensed weight changes of the apparatus that could heretofore systematically bias the determination. This double cam system has been implemented and the concept successfully demonstrated. This development is being carried out as a part of an ongoing CRADA with Micro-g Solutions, the commercial supplier of our previously developed FG-5 gravimeter. (J.E. Faller).

■ **Gravity Measurement.** The nearly 1% discrepancy between the recent PTB results and the "accepted" value of "big" G, the Newtonian constant of gravitation, is of considerable interest to the standards community. The fact that the PTB measurement appears to have been competently and thoughtfully carried out makes the discrepancy even more intriguing. NIST personnel, along with collaborators from the National Geodetic Survey, Micro-g Solutions, and JILA, have used an FG-5 absolute gravimeter together with a moveable 500 kg tungsten mass which surrounds the dropping chamber to measure G through the effect this large mass has on the measured value of g in the free-fall region. The measurement has been carried out and the data analysis is now completed. Though the idea of measuring the small mass-induced Δg effect on top of g itself might appear almost impossibly difficult, the fact that the signal can be modulated by moving the source mass every 10 or 20 min to either increase or decrease the measured value of g makes it possible to measure well into the noise floor. Though the "expected" accuracy (given the integration time and the expected FG-5 precision) should be 5 or 6 parts in 10^4, instrumental drifts of unknown origin have limited the accuracy obtained to about 0.14%. The final result is in reasonable agreement with the presently accepted CODATA value and does not support the PTB outlying value. However, the value is about 0.2% higher than the CODATA value which, incidentally, puts us a bit closer to the PTB result. (J.E. Faller)

■ **Non-linear Dynamics of Intense Femtosecond Pulse Propagation.** A clear picture of the propagation of femtosecond laser pulses is fundamentally important to many scientific and technological applications. Although some applications rely primarily on the delta-function qualities of a femtosecond pulse (e.g., time-resolved gating, transmission of binary data), at a more fundamental level pulse propagation encompasses much more than the simple transport of energy. It is a basic fact of the Maxwell equations that the manner in which a field propagates is fundamentally tied (via the polarization) to the properties of the medium in which it travels. From the standpoint of femtosecond diagnostics, this implies that if the electric field can be accurately characterized after propagation through a medium of interest, then valuable information about the medium and the propagation process may be obtained. Work has focused on both measuring and modeling the non-linear dynamics of the propagation of intense femtosecond pulses in bulk media.

Measurements of the fields of such pulses have been performed with frequency-resolved optical gating (FROG), providing a means to observe the evolution of both the temporal amplitude and phase of femtosecond pulses as they undergo rapid broadening and splitting while propagating in fused silica. These accurate measurements have initiated the development of a more complete, modified, non-linear Schrödinger equation (NLSE), which includes contributions of physical mechanisms such as Raman non-linearities, space-time coupling, nonlinear shock effects, and non-paraxiality. The improved model successfully predicts temporal asymmetries observed in the measurements. In addition, the technique of spectral interferometry has been applied to full beam measurements, permitting the measurement of the full (temporal plus spatial) electromagnetic field on a femtosecond time scale for the first time. (T.S. Clement).

Bose-Einstein Condensation. When a gas is made sufficiently cold, it undergoes a phase transition into a Bose-condensed state: the sample becomes highly coherent, with most of the atoms participating in a macroscopic common wavefunction. The atoms in a condensate are in close analogy with photons in a laser beam. It was NIST/JILA scientists in 1995 who first observed the phenomenon of Bose-Einstein condensation in a gas. Since then the field has grown very rapidly, to the point where there are now hundreds of technical papers published every year on the topic.

Work at JILA on BEC in the past year has concentrated in two main areas, tunable interactions and mixed condensates.

Tunable interactions: Many of the properties of a Bose-Einstein condensate are determined by the interactions between atoms. To the extent one can deliberately modify the nature of the interactions, one has intimate control over the behavior of the condensate. JILA theorists predicted that in the presence of an ambient magnetic field of about 15.0 mT (150 gauss), two-body interactions between Rb-85 atoms should go through a resonance. Experiments at JILA recently confirmed that the rate of elastic collisions between two ultracold Rb-85 atoms in a 15.5 mT (155 gauss) field is at least a factor of 10,000 higher than it is in a 16.7 mT (167 gauss field). The 16.7 mT magnetic fields at the heart of an atomic collision are on the order of tens of Tesla (hundreds of thousands of gauss). That a mT change in the ambient field could have such a profound effect on a collision says a lot about the power of resonance effects in ultracold collisions. Efforts are now underway to create a condensate in Rb-85 in order to exploit this so-called "Feshbach resonance" in BEC studies.

Mixed Condensates: A series of studies on the behavior of condensate mixtures has been performed, with the two components corresponding to two different hyperfine states of Rb-87. Interestingly, the same atomic physics theory that predicts the "pressure" in the condensate (the self-repulsion of the condensate atoms) also yields a prediction for the pressure-shift of the Rubidium clock transition. Thus, some of JILA's fluid-dynamical studies on mixed condensates have provided a sensitive confirmation of the accuracy of the atomic theory that predicts the ultimate limit to the accuracy of Rubidium-based atomic clocks. (E.A. Cornell).

Cooling a Dilute Gas of Fermionic Atoms to Quantum Degeneracy. Substantial progress has been made toward the goal of cooling a dilute gas of fermionic atoms to quantum degeneracy. Building on techniques used to produce BEC in a dilute atomic gas, we have implemented a double-MOT apparatus for cooling and trapping potassium. It has a fermionic isotope in addition to two that are bosons. Features of the apparatus include the use of diode lasers exclusively and the successful implementation of a novel, enriched source for the fermionic isotope ^{40}K. In the first stage of cooling, we have trapped ^{40}K atoms in a magneto-optical trap (MOT) with four orders of magnitude higher number of atoms than any previous work. In preparation for the second stage of cooling, we have transferred 70% of these atoms into a magnetic trap, and seen lifetimes that are sufficiently long for successful evaporative cooling. Since evaporative cooling depends heavily on elastic collision rates that are not well known for potassium, we are performing measurements of cold collision rates and observing the suppression of s-wave collisions in a spin-polarized sample due to Fermi-Dirac statistics. Once quantum degeneracy is reached, additional effects of the quantum statistics and the formation of a Fermi sea will be studied through measurements of thermodynamics, light scattering, and collisional properties of the dilute fermionic gas. (D.S. Jin).

Strontium Atom Trapping. Strontium atom trapping offers some outstanding opportunities for metrology and studying the physics of cold collisions. Since Sr singlet states have no fine structure and the principle isotope has no hyperfine structure, Sr provides exceptionally clean cut tests of trap collision theories. The triplet states of Sr offer an opportunity for analysis of trap behavior, very low temperature cooling, metrology and possibly Bose condensation without evaporative cooling. We have developed a Sr trap, based on resonance-line trapping from a thermal vapor in a sapphire-window cell. Trap loss due to leakage of excited 5^1P atoms (Sr*) to the triplet manifold is prevented with lasers that recycle metastable atoms back to the ground state, resulting in high trapped-atom densities and storage times. The trap velocity distribution is nondestructively measured using intercombination line fluorescence, which allows an exacting study of the dependence of trap temperature and cloud-cooling rates on detuning and power of the trapping beams. From the transient response of resonance-line and intercombination-line fluorescence, we deduce the various radiative rates within the lowest nine states of Sr. We have also determined the Sr-Sr* collisional loss rate coefficient from trap-loading time dependence and power and density dependencies. This is dominated by excitation of the attractive, non-radiating molecular state, which gains a dipole moment at large atomic separation due to radiation retardation. This provides an exceptionally sensitive test of retardation effects in molecular spectra, as well as of trap loss theories due to the exactly known molecular potentials. Atoms trapped at mK temperatures in the resonance-line trap are also transiently loaded into an intercombination-line trap with ~50% efficiency using broad-band, red-detuned cooling. This yields high Sr densities at μK temperatures, as well as the opportujity to measure cooling rates and unique forms of Ramsey fringes. (A.C. Gallagher).

■ **Particle Growth in Thin-Film Deposition Discharges.** Particles grow in the discharges used to deposit thin semiconducting films. Some of these particles escape to the films, causing a deterioration in their electronic properties. To understand the causes and behavior of these particles, their growth and transport to the substrate has been studied in the types of discharges used to make amorphous silicon, thin-film transistors and photovoltaics. Light scattering by the suspended particles, during and immediately after extinguishing the discharge, has been analyzed to yield particle growth rates and densities for the very small particles (<30 nm diameter) that escape to the films. This has yielded clear insights regarding the species trapped in the discharge and the reactions causing them to grow. These results have also demonstrated that particle trapping and growth is an inevitable consequence of the plasma chemistry used to produce the films. However, this does not mean that particles will inevitably escape to the growing films. The observations and related models have identified important spatial variations in plasma potential, as well as thermophoretic effects, that can be used to mitigate the escape of particles to the films. (A.C. Gallagher).

FUTURE DIRECTIONS

■ **Ultrafast Soft X-Rays.** A table top soft x-ray laser operating at 1000 Hz has been developed to study time-resolved x-ray photoelectron spectroscopy of dissociating and reacting systems. An ultrafast laser system operating on Ti:sapphire at 800 nm produces 2.5 mJ at 1000 Hz, with 75 fs pulse duration. The ultrafast laser is focused into a jet of neon rare gas, also pulsed at 1000 Hz. High harmonics are generated up to about 90 eV photons. The harmonics are separated with a grazing incidence grating and approximately 3 billion photons per sec are estimated thus far at 80 eV. In new experiments, these photons will be used to probe the core level x-ray photoelectron spectra of atoms in dissociating molecules and clusters. (S.R. Leone).

■ **Single Molecule and Single Quantum Dot Confocal Microscopy.** In close conjunction with the NSOM efforts, we are developing new capabilities in high sensitivity detection and spectroscopic characterization of single molecules. This is based on laser excitation and fluorescence detection via scanning confocal microscopy, coupled with a high sensitivity, CCD array spectrometer. Most recently, we have been using this new capability to investigate the photobleaching dynamics of individual dye molecules, green fluorescence protein, and CdSe quantum dots. Our long-range interest is in developing methods to optically tag biomolecules at single molecule sensitivity and high spatial resolution for probing physical properties of biopolymers. Particularly interesting is the observation of multiple time scales for fluorescence from individual quantum dots, ranging from the fast radiative and nonradiative recovery on the ns time scale to so called "blinking" fluorescence intermittency due to multiphoton ionization of single quantum dots on the msec to sec time scale. (For example, see cover figure for this section.) (D.J. Nesbitt).

■ **Coherent Phenomena in Optically Dense Material.** Coherent phenomena in semiconductors have been the subject of significant research during the last decade due to the development of lasers capable of producing pulses with widths below 1 ps. The general understanding of coherent phenomena is derived from extensive work in dilute atomic vapors. Semiconductors display new phenomena and modifications to well known phenomena. Some of these are due to the large optical density; others are unique to the many-body interactions among mobile carriers. Coherent phenomena are not well understood in dense atomic vapors either. Experiments are being set up to explore coherent phenomena in semiconductors and dense atomic vapors. Comparison of the phenomena in the two media should yield interesting insights. (S.T. Cundiff).

■ **Nonlinear Spectroscopy of Mixed-Valent Materials.** Mixed valent materials have a band of strongly localized f-electrons energetically overlapping a conduction band of itinerant d-electrons. The interaction results in strong electron correlation and the opening of an energy gap. Electron correlation is important in many solids of current interest, including high T_c superconductors, colossal magneto-resistance materials, Mott insulators and Kondo insulators. Recent theoretical results predict that electron pairing should occur, leading to ferroelectric behavior and a breaking of the inversion symmetry present in the crystal structure. This will imbue the material with a second order, nonlinear, optical response. The nonlinear optical response will be resonantly enhanced near the gap energy, which is about 10 meV. Experiments are being set up to search for this nonlinearity using intense pulses of THz radiation. The THz pulses are generated using photoconductive emitters excited by ultrashort optical pulses. (S.T. Cundiff).

■ **Guided-Atom Optics.** A new generation of atom-guiding technology is currently in development. Atoms will be guided by the magnetic fields generated by the electrical currents in a pair of lithographically patterned wires. The atoms will "fly" just a few microns above the substrate, much like the cars of a miniature, magnetically levitated train. This work is an offshoot of the ongoing QPD experiments in which atoms are optically guided inside of hollow glass fibers. The lithographic method used to pattern the "train tracks" will be readily extended to create "switches" (i.e., atomic beam splitters) and "loop-the-loops" (i.e., Sagnac-type circular atom interferometers.) Initial experiments will inject laser-cooled atoms into the guide; second generation experiments will couple-in Bose-Einstein condensates. Ultimately the technology will enable the construction of robust, large-area, atom-interferometers with enormous sensitivity to electric, magnetic, and gravitational fields and to various spatial and temporal gradients of those fields. (E.A. Cornell).

■ **W.M. Keck Optical Measurement Laboratory.** JILA has received a grant from the W.M. Keck foundation to establish an Optical Measurement Laboratory. It will support ongoing NIST research in many areas, including that on Bose-Einstein condensation, ultrafast optical processes, optical nano-material science, and near field scanning microscopy. This state-of-the-art facility will encompass three main areas: optical materials preparation, nanofabrication, and laser characterization. A clean area is being constructed and a suite of instrumentation is being assembled to provide the required new capabilities. ❑

APPENDIX A

PUBLICATIONS

A

PUBLICATIONS

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Wieman, C.E. and Cornell, E.A., "Bose-Einstein condensation in a cold vapor," in *King Faisal Award Proc.* (in press).

Williams, J., Walser, R., Cooper, J., Cornell, E.A., and Holland, M., "Nonlinear Josephson-type oscillations of a driven, two-component Bose-Einstein condensate," Phys. Rev. Lett. **59**, R31-34 (1998).

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Ye, J., Ma, L.-S., and Hall, J.L., "Cavity-enhanced frequency modulation spectroscopy: Advancing optical detection sensitivity and laser frequency stabilization," in *Methods for Ultrasensitive Detection,* ed. by Fearey, B.L., SPIE Proc. **3270** (in press).

Ye, J., Ma, L.-S., and Hall, J.L., "Using FM methods with molecules in a high finesse cavity: a demonstrated path to $<10^{-12}$ absorption sensitivity," in *Ultrasensitive Detection* (ed. by Busch, K. and Busch, M., American Chemical Society, in press).

NOTE: Names in parentheses are authors who are not connected with JILA. The list does not include JILA publications by JILA CU Fellows and their associates. ◻

APPENDIX B

INVITED TALKS

B

INVITED TALKS

LABORATORY OFFICE

Gebbie, K.B., "Careers in Government: From Bench Scientist to Policy Wonk," 1998 Joint American Physical Society/American Association of Physics Teachers Meeting, Columbus, OH, April 1998.

Gebbie, K.B., "Beyond the Ivory Tower: Careers in Government. From Bench Scientist to Policy Wonk," Physics Department, California Institute of Technology, Pasadena, CA, October 1998.

Gebbie, K.B., "Careers in Science: More Than One Dimension," Joint Ohio Section Fall Meeting of American Physical Society/ American Vacuum Society, Akron, OH, October 1998.

Ott, W.R., "Metrology Education at NIST," International Conference on Engineering Education, Rio de Janeiro, Brazil, August 1998.

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Anderson, W.R., Bradley, C.C., McClelland, J.J., and Celotta, R.J., "Nanostructure Fabrication Through Laser Focused Deposition of Chromium," Motorola, Austin, TX, February 12, 1998.

Anderson, W.R., Bradley, C.C., McClelland, J.J., and Celotta, R.J., "Nanostructure Fabrication Through Laser Focused Deposition of Chromium," Motorola, Phoenix, AZ, February 13, 1998.

Bergeson, S.D., Balakrishnan, A., Baldwin, K.G.H., Lucatorto, T.B., Marangos, J.P., McIlrath, T.J., O'Brian, T.J., Rolston, S.L., Sansonetti, C.J., Wen, J., and Westbrook, N., "Precision Spectroscopy in He as a Test of QED Calclulation," Vancouver, B.C., Canada, August 1998.

Bradley, C.C., "Atom Optics, Bose-Einstein Condensation and Nanolithography," Department. of Physics and Astronomy, University of Oklahoma, Norman, OK, January 29, 1998.

Bradley, C.C., "Atom Optics, Bose-Einstein Condensation and Nanolithography," Department. of Physics and Astronomy, University of Nebraska, Lincoln, NE, February 10, 1998.

Bradley, C.C., "Atom Optics, Bose-Einstein Condensation and Nanolithography," Department. of Physics, College of William and Mary, Wiliamsburg, VA, March 2, 1998.

Bradley, C.C., "Atom Optics, Bose-Einstein Condensation and Nanolithography," Texas Christian University, Fort Worth, TX, March 5, 1998.

Bradley, C.C., "Atom Optics, Bose-Einstein Condensation, and Nanolithography," University of Delaware, Department. of Physics and Astronomy, Newark, DE, March 10, 1998.

Bradley, C.C., "Atom Optics, Bose-Einstein Condensation and Nanolithography," Physics Department, Yale University, New Haven, CT, March 19, 1998.

Bradley, C.C., "Atom Optics, Bose-Einstein Condensation, and Nanolithography," Physics Dept, University of Virginia, Charlottesville, VA, March 23, 1998.

Bruun, G., "Superconductivity in an Ultra-Cold Atomic Gas," Chemical Physics Seminar, University of Maryland, College Park, MD, November 4, 1998.

Celotta, R.J., "Magnetic Nanostructures," Laboratory for Surface Modification, Rutgers University, Piscataway, NJ, April 30, 1998.

Celotta, R.J., "Recent Advances in Nanolithography via Atom Optics," Max-Planck-Institute for Microstructure Physics, Halle, Germany, May 26, 1998.

Celotta, R.J., "Nanofabrication via Atom Optics," International Symposium on Nanoscale Modification of Surfaces, Krakow, Poland, May 29, 1998.

Celotta, R.J., "Micro-magnetic Imaging," Spintronics '98, Lake Tahoe, CA, August 5, 1998.

Clark, C.W., "Structure and Spectra of Bose-Einstein Condensates," Atomic Physics Seminar, University of Southern California, Los Angeles, CA, March 19, 1998.

Clark, C.W., "Bose-Einstein Condensation, the Atom Laser, and Nanokelvin Thermometry," Distinguished LMS Lectureship, Laboratory for Molecular Sciences, California Institute of Technology, Pasadena, CA, March 20, 1998.

Clark, C.W., "Modern BEC from the AMO Perspective," Gordon Conference on Multiphoton Processes, Tilton, NH, June 18, 1998.

Clark, C.W., "Coherence Properties of Atom Lasers at Finite Temperature," 7th International Workshop on Laser Physics, Berlin, Germany, July 7, 1998.

Clark, C.W., "Structure and Spectra of Bose-Einstein Condensates," Supercomputing, Collision Processes and Applications, Queen's University of Belfast, Northern Ireland, September 14, 1998.

Clark, C.W., "Structure and Spectra of Bose-Einstein Condensates," Department of Physics and Astronomy Colloquium, University of Nebraska, Lincoln, NE, October 22, 1998.

Clark, C.W., "Structure and Spectra of Bose-Einstein Condensates," Atomic Physics Seminar, University of Virginia, Charlottesville, VA, November 23, 1998.

Davies, A.D., Stroscio, J.A., Pierce, D.T., and Celotta, R.J., "Atomic-scale Characterization of Magnetic Multilayers with Scanning Tunneling Microscopy," Physics Department Seminar, University of Arkansas, Fayetteville, AR, February 27, 1998.

Davies, A.D., Stroscio, J.A., Pierce, D.T., and Celotta, R.J., "Atomic-scale Spectroscopy of Transition Metal Surfaces," Gordon Conference on Electron Spectroscopy, Henniker, NH, July 7, 1998.

Feder, D., "The Search for Vortices in Trapped Bose Condensed Gases," Condensed Matter Physics Seminar, University of Delaware, Newark, DE, November 10, 1998.

Lucatorto, T.B., "Synchrotron Radiation for Radiometry," 1998 Optical Society of America Annual Meeting, Baltimore, MD, Oct. 6, 1998.

McClelland, J.J., "Using Atom Optics to Build Nanostructures," APS Division of Atomic, Molecular, and Optical Physics Conference, Santa Fe, NM, May 29, 1998.

Pierce, D.T., "Application of the STM to Understanding Magnetic Nanostructures," Gordon Research Conference on Magnetic Nanostructures, Ventura, CA, January 24, 1998.

Pierce, D.T., "Exchange Coupling of Magnetic Layers," Physics Dept., McGill University, Montreal, Canada, March 6, 1998.

Pierce, D.T., Davies, A.D., Celotta, R.J., and Stroscio, J.A., "Consideration on Using GaAs tips for Spin Polarized Scanning Tunneling Microscopy," Low Energy Polarized Electron Workshop, St. Petersburg, Russia, September 3, 1998.

Pierce, D.T., "Round Table Discussion: Polarimeters Based Upon Spin-dependent Electron Absorption," Low Energy Polarized Electron Workshop, St. Petersburg, Russia, September 4, 1998.

Pierce, D.T., "Exchange Coupling of Magnetic Layers," Seminar: Institute for Surface and Interface Science, UC-Irvine, CA, October 8, 1998.

Reinhardt, W.P., "Solitons and Vortices in Attractive and Repulsive Atom Bose-Einstein Condensates," Physics Colloquium, Univ. of Maryland, College Park, MD, October 20, 1998.

Stiles, M.D. and McMichael, R.D., "Model for Exchange-biased Magnetic Layers," The Johns Hopkins Univ., Baltimore, MD, May 27, 1998.

Stroscio, J.A., Davies, A.D., Pierce, D.T., and Celotta, R.J., "The Role of the Interface in the Exchange Coupling of Magnetic Layers," 14th International Vacuum Congress, Birmingham, England, September 9, 1998.

Unguris, J., "SEMPA: Tutorial on Magnetic Imaging," 7th Joint Magnetism and Magnetic Materials/Intermag Conference, San Francisco, CA, January 5, 1998.

Unguris J., "SEMPA Studies of Ultrathin Film Magnetism," Symposium on Microstructure and Microscopy of Magnetic Materials, Iowa State University, Ames, Iowa, May 14, 1998.

Unguris, J., Celotta, R.J., Tulchinsky, D.A., and Pierce, D.T., "Exchange Coupling in Magnetic Multilayers Grown on Iron Whiskers," Third International Symposium on Magnetic Multilayers, Vancouver, Canada, June 18, 1998.

Vest, R.E., "Radiation Safety and Scientific Programs at SURF," Baltimore-Washington Chapter of the Health Physics Society Technical Meeting, Gaithersburg, MD, May 1998.

ATOMIC PHYSICS DIVISION (842)

Bryant, G.W., "Near-Field Optics: Nano-Optical-Metrology for Nanosystems," LAMOSE (Laboratory for Atomic, Molecular and Optical Science and Engineering, University of Maryland, February, 1998.

Burnett, J.H., "Ultraviolet Source and Detector Radiometry in Semiconductor Production Microlithography," SPIE's 23rd Annual International Symposium on Microlithography, Santa Clara, California, February 1998.

Deslattes, R.D., "Perfect Crystals and Fundamental Metrology," Micro Gravity Materials Science and Applied Division colloquium at the Univ. Space Res. Assoc., NASA Marshall Flight Center in Huntsville, AL, February 18, 1998.

Deslattes, R.D., "High Resolution Gamma-Ray Spectroscopy: The First 85 Years," Keynote presentation at the Applications of High-Precision Gamma-Spectroscopy Meeting, Notre Dame, IN, July 1, 1998

Deslattes, R.D., "The Molar Volume of Silicon: Discrepancies and Limitations," Conference on Precision Electromagnetic Measurements (CPEM 98), Washington, DC, July 7, 1998.

Deslattes, R.D., "Just How Perfect Can a Perfect Crystal Be?" 4th European Conference on High Resolution X-ray Diffraction and Topography, University of Durham, Durham, U.K. Sept. 9-11, 1998.

Deslattes, R.D., "The Molar Volume Anomaly," Avogadro Group Meeting, IRRM, Geel, Belgium, November 1997.

Deslattes, R.D., "What in the World is Wrong with the Kilogram?" Physics Colloquium at Cornell University, Ithaca, NY, November 1998.

Gillaspy, J.D., "Little Ions with a Big Charge", Annual Meeting of Sigma Xi, Vancouver, British Columbia, Canada, November 14, 1998.

Helmerson, K., "Atom Optics with BEC," Modern Optics Seminar, Massachusetts Institute of Technology, Cambridge, MA, October 1998.

Helmerson, K., "Atom Optics with BEC," Workshop on Cooperative Effects in Quantum Systems, University of Illinois, Urbana-Champaign, IL, November 1998.

Helmerson, K., "Colliding Biological Objects Using Optical Tweezers: A New Technique for Studying Adhesion," Annual Meeting of the Adhesion Society, Savannah, GA, February 1998.

Helmerson, K., "Manipulation of BEC by Optical Laser Pulses," International School of Physics "Enrico Fermi," Course CXL on Bose-Einstein Condensation in Atomic Gases, Varenna, Italy, July 1998.

Helmerson, K., "Dual Optical Tweezers for Adhesion Studies," Annual Meeting of the Biomedical Engineering Society, Cleveland, OH, October 1998.

Julienne, P.S., "Collisions and Bose-Einstein Condensation," School on Nonlinear and Quantum Optics, 1998, Sao Carlos, Brazil, January 5-16, 1998.

Julienne, P.S., "Introduction to Cold Collisions: Basic Concepts," School on Nonlinear and Quantum Optics, 1998, Sao Carlos, Brazil, January 5-16, 1998.

Julienne, P.S., "Photo-induced Collisions," School on Nonlinear and Quantum Optics, 1998, Sao Carlos, Brazil, January 5-16, 1998.

Julienne, P.S., "Progress in Cold Collision Studies for Bose-Einstein Condensation," Mini-workshop on Bose-Einstein Condensation, Niels Bohr Institute, Copenhagen, Denmark, January 24, 1998.

Julienne, P.S., "Collisions in a Cold Atomic Gas," Euroconference on Slow Collisions between Laser Manipulated Systems, Rust, Austria, April 1-5, 1998.

Julienne, P.S., "Cold Molecule Formation in Bose-Einstein Condensates and Optical Lattices," Center for Advanced Studies Workshop on Quantum Control of Atomic Motion II, University of New Mexico, Albuquerque, New Mexico, June 1-2, 1998.

Julienne, P.S., "Lineshape Issues in Cold Atomic Collisions," International Conference on Spectral Line Shapes, Pennsylvania State University, State College, PA, June 22-26, 1998.

Julienne, P.S., "Atoms, Molecules, Bose-Einstein Condensates, and Light," Gordon Conference on Atomic and Molecular Interactions, New London, NH, June 28-July 3, 1998.

Julienne, P.S., "Ultracold Atomic Collisions," International Conference on Atomic Physics, Windsor, Ontario, Canada, August 3-7, 1998.

Julienne, P.S., "Atoms, Light and Bose-Einstein Condensates: The Story of Cooling and Trapping," Physics Seminar, George Mason University, Fairfax, VA, October 9, 1998.

Julienne, P.S., "Cold Atomic Collisions: nine lectures," Master Class on Laser Cooling, Cold Collisions, and Bose-Einstein Condensation, Niels Bohr Institute, Copenhagen, Denmark, December 2-9, 1998.

Kelleher, D.E. and Wiese, W.L., "Critical Evaluation of Atomic Transition Probabilities," NASA Laboratory Space Science Workshop, Harvard Smithsonian Center for Astrophysics, April 1-3, 1998.

Kelleher, D. E., The NIST Atomic Spectra Database, Sixth International Colloquium on Atomic Spectra and Oscillator Strengths, Victoria, B.C., August 9-13, 1998.

Kessler, E.G., Jr., "Precision Measurements of Fundamental Constants Using GAMS 4," Applications of High-Precision Gamma Spectroscopy Meeting, Notre Dame, IN, July 1, 1998

Kessler, E.G., Jr., Owens, S., Henins, A., and Deslattes, R.D., "Silicon Lattice Comparisons Related to the Avogadro Project: Uniformity of New Material and Surface Preparation Effects," Conference on Precision Electromagnetic Measurements (CPEM 98), Washington, DC, July 7, 1998.

Kim, Y.-K., "Atomic Cross Sections for X-Ray Laser Modeling," Kansai Center, Japan Atomic Energy Research Institute, Osaka, Japan, February 5, 1998.

Kim, Y.-K., "Relativistic Atomic Structure Calculations," Dept. of Applied Physics and Chemistry, Univ. of Electro-Communications Univ., Chofu, Japan, February 13, 1998.

Kim, Y.-K., "Electron-Impact Ionization of Molecules," Chemistry Dept., Tokyo Inst. of Technology, Tokyo, Japan, February 16, 1998.

Kim, Y.-K., "Electron-Impact Ionization of Atoms and Molecules," Physics Dept., Sophia University, Tokyo, Japan, February 17, 1998.

Kim, Y.-K., "Electron-Impact Ionization of Molecules," Institute for Molecular Science, Okazaki, Japan, February 18, 1998.

Kim, Y.-K., "Atomic Cross Sections for Fusion Applications," National Inst. of Fusion Science, Toki, Japan, February 20, 1998.

Kim, Y.-K., "Relativistic Atomic Structure Calculations," Physics Dept., Nara Women's University, Nara Japan, February 27, 1998.

Kim, Y.-K., "Electron-Impact Ionization Cross Sections of Molecules," Workshop on Electron-Molecule Collision Data for Modeling and Simulation of Plasma Processing, Lyon, France, September 23, 1998.

Kim, Y.-K., "Electron-Impact Ionization of Molecules: An *ab initio* Theory," Department of Chemistry and Biochemistry, University of Maryland, September 30, 1998.

Kim, Y.-K., "Introductory Atomic Structure Theory," Physics Department., Seoul National University, Seoul, Korea, October 28, 1998.

Kim, Y.-K, "Electron-Atom Collisions," Physics Department., Seoul National University, Seoul, Korea, October 28, 1998.

Kim, Y.-K., "Introductory Atomic Collision Theory," Physics Department., Seoul National University, Seoul, Korea, October 29, 1998.

Kim, Y.-K., "Failure of Single-Configuration Dirac-Fock Wave Functions in the Nonrelativistic Limit," 6th Symposium on Laser Spectroscopy, Taejon, Korea, November 3-4, 1998.

Kim, Y.-K., "The World of Atoms," Physics Dept., Korea Advanced Inst. of Science and Technology, November 5, 1998.

Kulin, S., "Exotic Quantum States in Ultracold Atom Manipulation," Annual Meeting of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society, Santa Fe, NM, May 1998.

Kulin, S., "Transport in Three Dimensional Optical Lattices, Quantum Control of Atomic Motion II," Center for Advanced Studies Workshop, Albuquerque, NM, June 1998.

Lett, P.D., "Laser Cooling and the 1997 Nobel Prize in Physics," Physics Department Seminar at Creighton University, Omaha, NE, March 1998.

Lett, P.D., "Photoassociation Spectroscopy and Low-Energy Collisions in Na and Xe*," ESCOLAR '98, Rust, Austria, April 1998.

Lett, P.D., "Laser Cooling and Trapping: Games with Atoms Near Absolute Zero," Physics Department Colloquium at Swarthmore College, Swarthmore, PA, November 1998.

Lett, P.D., "Photoassociation Spectroscopy: The Life and Times of Atoms, as Told by Molecules," Chemical Physics Seminar at Penn State University, State College, PA, November 1998.

Mohr, P.J., "Fundamental Constants and QED," University of Notre Dame, South Bend, IN, April, 1998.

Mohr, P.J., "QED Tests and Fundamental Constants," Workshop on Frontier Tests of Quantum Electrodynamics and Physics of the Vacuum, Bulgaria, June 1998.

Mohr, P.J., "The Fundamental Constants as of 1998," International Conference on Trapped Charged Particles and Fundamental Physics, Monterey, CA, September 1998.

Ovchinnikov, Yu.B., "Gravito-Optical Atom Trap Based on a Conical Hollow Beam," International Quantum Electronics Conference, San Francisco, CA, May 1998.

Ovchinnikov, Yu.B., "Pulsed Three Light Grating Interferometer with Bose-Einstein Condensate," Quantum Control of Atomic Motion II, Albuquerque, NM, June 1998.

Pedulla, J., Owens, S., and Deslattes, R.D, "X-Ray Specular and Diffuse Scatter Characterization of Near Ideal Thin Film Multilayers on Various Substrates Produced by Dual Ion Beam Deposition," 4th International Conference on the Physics of X-Ray Multilayer Structures, Breckenridge, CO, March 1-5, 1998.

Pedulla, J., "X-Ray Reflectivity" Gatestack Engineering Working Group, SEMATECH, Austin Texas, July 23, 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Junior Science and Humanities Symposium, Georgetown University, Washington, DC, January 1998.

Phillips, W.D., "The 1997 Nobel Prize in Physics," Standards Alumni Association, National Institute of Standards and Technology, Gaithersburg, MD, January 1998.

Phillips, W.D., "Hands-On Science," DOE-Energy Council on Community Service, Kickoff Program, Darnestown Elementary School, Darnestown, MD, January 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Institute for Defense Analyses, Alexandria, VA, February 1998.

Phillips, W.D., "Optical Lattices," Colloquium at the University of Washington, Seattle, WA, February 1998.

Phillips, W.D., "Optical Lattices," Colloquium at the University of Maryland, College Park, MD, February 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Department of Physics Colloquium, Princeton University, Princeton, NJ, March 1998.

Phillips, W.D., "Cooling, Trapping and the Nobel Prize," McKinley Elementary School, Arlington, VA, March 1998.

Phillips, W.D., "Optical Lattices," Colloquium at Williams College, Williamstown, MA, March 1998.

Phillips, W.D., "Time, Einstein, and the Coldest Stuff in the Universe," Colloquium at Williams College, Williamstown, MA, March 1998.

Phillips, W.D., "Weirdness in Quantum Mechanics," Colloquium at Williams College, Williamstown, MA, March 1998.

Phillips, W.D., "Time, Einstein, and the Coldest Stuff in the Universe," Oklahoma State, Stillwater, OK, April 1998.

Phillips, W.D., "Optical Lattices: Atomic Physics Meet Solid State," Oklahoma State, Stillwater, OK, April 1998.

Phillips, W.D., "The 1997 Nobel Prize in Physics," Oklahoma State, Stillwater, OK, April 1998.

Phillips, W.D., "Optical Lattices: Atomic Physics Meet Solid State," APS Meeting, Columbus, OH, April 1998.

Phillips, W.D., "Cooling, Trapping and the Nobel Prize," Talk at Dufief Elementary School, Gaithersburg, MD, April 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Physics Department Colloquium, University of Virginia, Charlottesville, VA, April 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Public Speech, Messiah College, Mechanicsburg, PA, April 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Lecture at Ohio State, Columbus, OH, April 1998.

Phillips, W.D., "The Excitement of Science," Montgomery County Science Fair Awards Ceremony at the National Institute of Standards and Technology, Gaithersburg, MD, April 1998.

Phillips, W.D., "The Excitement of Science," Talk at Hoover and Schaeffer Elementary Schools, Camp Hill, PA, May 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," CLEO/IQEC Meeting, San Francisco, CA, May 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," DAMOP, Santa Fe, NM, May 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Naval Research Laboratory, Washington, DC, June 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Talk at Universita di Firenze, Florence, Italy, June 1998.

Phillips, W.D., "Cold Atoms and Condensed Matter Physics: Optical Lattices and SEC," National Conference on the Physics of Matter, Rimini, Italy, June 1998.

Phillips, W.D., "Commencement Speech," Richard Montgomery High School Graduation, Washington, DC, June 1998.

Phillips, W.D., "The 1997 Nobel Prize in Physics," Darnestown Civic Association Meeting, Darnestown, MD, June 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Talk at University of Potenza, Potenza, Italy, July 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Gave Colloquium at the Universita di Napoli, Naples, Italy, July 1998.

Phillips, W.D., "Bose-Einstein Condensation at NIST-Gaithersburg," Talk at Ecole Normale Superieure, Paris, France, July 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," SURF Student Talk, National Institute of Standards and Technology, Gaithersburg, MD, July 1998.

Phillips, W.D., "Precision Measurements with Laser Cooled Atoms," CPEM Meeting, Washington, DC, July 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Lecture at NEC, Princeton, NJ, August 1998.

Phillips, W.D., "Optical Lattices, Bose-Einstein Condensation and What's New in Laser Cooling," ICAP Conference, Windsor, Canada, August 1998.

Phillips, W.D., "Schawlow Prize Lecture" OSA/ILS Conference, Baltimore, MD, October 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Columbia University, New York, NY, October 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Lecture at Hood College, Frederick, MD, October 1998.

Phillips, W.D., "Atom Optics with Bose Condensates," Yale University, New Haven, CT, October 1998.

Phillips, W.D., "Second Annual Katzenstein Distinguished Lecture," University of Connecticut, Storrs, CT, October 1998.

Phillips, W.D., "Sir Run Run Shaw Distinguished Lecture," State University of New York at Stony Brook, Stony Brook, NY, October 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Queens University, Kingston, Canada, November 1998.

Phillips, W.D., "Nobel Lecture," Texas A&M University, College Station, TX, November 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Naval Air Warfare Center, Lexington Park, MD, December 1998.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping of Atoms," Colloquium at the University of Rochester, Rochester, NY, December 1998.

Phillips, W.D., "Nobel Lecture," University of Arizona, Tucson, AZ, December 1998.

Rolston, S.L., "Optical Lattices, Magnetic Trapping, and Bose Einstein Condensation," 5 lectures at the Latin American Summer School of Physics, Mexico City, Mexico, August 1998.

Rolston, S.L., "Atom Optics with Bose Condensates," South Eastern Section of the American Physical Society, Miami, FL, November 1998.

Tang, C.-M., "Beam Focusing for Field Emission Display," Field Emission Display Workshop, 1998 International Display Research Conference and SID Asia Display '98, Seoul, Korea, September 29-October 1, 1998.

OPTICAL TECHNICAL DIVISION (844)

Benedict, L.X., "Iterative Computation of Optical Absorption Including the Electron-Hole Interaction," Tenth Annual Workshop on Recent Developments in Electronic Structure Algorithms, University of Pennsylvania, Philadelphia, PA, May 1998.

Datla, R., "Current NIST Involvement in Cryogenic Radiometry and Space Applications," Seminar speaker at VNIIOFI, Moscow, Russia, November 1998.

Datla, R., "High Accuracy Space Based Radiometry - Strategies for Standardization," First International Conference on Small Satellites, New Technologies, Achievements, Problems and Prospects for International Cooperation in the New Millenium, Korolyov, Moscow Region, Russia, November 1998.

Datla, R., "On Orbit Radiometry for Space Based Sensors," Infrared Radiometric Sensor Calibration Symposium, Logan, UT, September 1998.

Datla, R., "Recommended practice for radiometric sensor calibration," Seminar speaker at the Metrology Laboratory of Hungary, Budapest, Hungary, November 1998.

Fraser, G.T., "Characterization of the Microwave Emission from SURF II," Advanced Photon Source, Argonne, IL, July 1998.

Fraser, G.T., "Infrared Spectroscopic Studies of Wind Tunnel Contamination," AEDC Wind Tunnel 9, White Oak, MD, January 1998.

Fraser, G.T., "Investigation of the Spectra of Atmospheric Molecules," UConn/Wesleyan/Yale Chemical Physics Seminar and University of Connecticut Department of Chemistry Colloquim, Storrs, CT, February 1998.

Germer, T.A., "Application of Bidirectional Ellipsometry to the Characterization of Roughness and Defects in Dielectric Layers," presented to the "Optical Scattering in the Wafer, Flat Panel Display, and Magnetic Disk Industries II," conference at Photonics West, San Jose, CA, January 1998.

Germer, T.A., "Bidirectional Ellipsometry of High Aspect Ratio Vias: Progress Report," to the SEMATECH Defect Detection and Analysis PTAB meeting, in Austin, TX, April 1998.

Germer, T.A., "Polarization of out-of-plane Optical Scatter from SiO_2 Films Grown on Photolithographically-generated Microrough Silicon," to the conference entitled "Scattering and Surface Roughness II" at the SPIE Annual Meeting, San Diego, July 1998.

Germer, T.A., "Polarized Light Scattering from Bare Wafers, Wafers with Dielectric Layers, and High Aspect Ratio Vias," to the Orbot Division of Applied Materials, Yavne, Israel, June 1998.

Germer, T.A., "Polarized Light Scattering from Roughness, Defects, and Particles on Silicon Wafers," presented at the Optical Society of America Annual Meeting, Baltimore, MD, October 1998.

Germer, T.A., "Polarized Light Scattering Measurements of the HP Test Wafer," presented to the SEMATECH Defect Detection and Analysis PTAB meeting, Austin, TX, on September 1998.

Goldner, L.S., "Domains And Dynamics In Thin Films Studied By NearField Microscopy," LAMOSE (Laboratory for Atomic, Molecular and Optical Science and Engineering, University of Maryland), April 1998.

Hanssen, L.M., "NIST FTIR Laboratory for Infrared Optical Properties Characterization: Current Status," Symposium on Infrared Radiometric Sensor Calibration, Logan, Utah, September 1998.

Heilweil, E.J., "Application of Broadband Ultrafast Infrared Spectroscopy," Advanced Infrared and Raman Spectroscopy (AIRS III), Berhardt Lendl, Technical University, Chair, Vienna, Austria, July 1998.

Heilweil E.J., "Applications of Transient Infrared Spectroscopy and Imaging," Western Spectroscopy Association, 45th Annual Meeting, Asilomar Conference Center, Pacific Grove, CA, January 1998.

Heilweil, E.J., "Applications of Ultrafast Infrared Spectroscopy: Hydrogen Bonding, Vibrational Control and THz Measurements," 61st Okazaki Conference on "Liquid Dynamics Studied by Time-Resolved Vibrational Spectroscopy," Institute for Molecular Spectroscopy, Okazaki, Japan, January 1998.

Heilweil, E.J., "Broadband Time-Resolved Infrared Spectroscopy and Imaging for Chemical Applications," Northwest Regional OSA Meeting, Portland, OR, May 1998.

Heilweil, E.J., "Broadband Time-Resolved Infrared Spectroscopy and Imaging for Chemical Applications," Department of Chemistry and Chemical Physics Institute, University of Oregon, Eugene, OR, May 1998.

Heilweil, E.J., "Far Infrared Spectroscopy of Proteins, DNA and Hydrogen-Bonded Systems," American Physical Society Annual Meeting, Division of Chemical Physics, session on "Aspects of THz Spectroscopy in Chemical Physics," Los Angeles, CA, March 1998.

Heilweil, E.J., "Ultrafast Transient Infrared Spectroscopy: Applications to Chemistry and Biology," CLEO/ILS short course #127, San Francisco, CA, May 1998.

Hougen, J.T., "Basic Theoretical Concepts Involved in Treating High-Barrier Multidimensional Tunneling in the Methanol Dimer $(CH_3OH)_2$," Department of Chemistry, Ohio State University "Frontiers in Spectroscopy," course series, February 1998.

Hougen, J.T., "Basic Theoretical Concepts Involved in Treating Low-Barrier Pseudorotation in the Sodium Trimer Na_3," Department of Chemistry, Ohio State University "Frontiers in Spectroscopy," course series, February 1998.

Hougen, J.T., "Symmetric Top Spectroscopy," Department of Chemistry, Tsing Hua University, Shin Chu, Taiwan, December 1998.

Hougen, J.T., "Symmetric Top Spectroscopy," Institute of Atomic and Molecular Sciences, Taipei, Taiwan, November, 1998.

Jacox, M.E., "Exploring the World of Molecular Ions," Department of Chemistry, Syracuse University, Syracuse, NY, February 1998.

Lafferty, W.J., "Supersonic Jet IR Spectra of the NO_2 Dimer with Striking Fermi Resonances," Seminar at Laboratoire de Photophysque Moleculaire, Universite de Paris, Orsay, March 1998.

Lorentz, S.R., "NIST BMDO Transfer Radiometer (BXR): Calibration Strategies and Transfer to the User Facilities," USU/SDL Symposium, Logan, UT, September 1998.

Lorentz, S.R., "NIST Low Background Infrared Facility Operations and Upgrades," USU/SDL Symposium, Logan, UT, September 1998.

Lorentz, S.R., "Si:As BIB Detector Characterization and Cryogenic Electronics for use with the NIST BMDO Transfer Radiometer," USU/SDL Symposium, Logan, UT, September 1998.

Migdall, A., "Measuring Polarization Mode Dispersion with Attosecond Resolution using Correlated Photons," University of Essex, Colchester, UK, June 1998.

Migdall, A., "Correlated Photon Based Absolute Metrology," OSRAM Sylvania, Beverly, MA, May 1998.

Migdall, A., "Correlated Photon Based Absolute Metrology," University of Innsbruck, Innsbruck, Austria, August 1998.

Migdall, A., "Correlated Photon Based Absolute Metrology," University of Geneva, Geneva, Switzerland, August 1998.

Migdall, A., "Correlated Photon Based Absolute Metrology," DRA, Malvern, UK, June 1998.

Migdall, A., "Correlated Photon Based Absolute Metrology," New England Section of the Optical Society and IEEE/LEOS, Waltham MA, May 1998.

Migdall, A., "Correlated Photon Based Absolute Metrology," Photonics Center, Boston University, Boston, MA, April 1998.

Migdall, A., "Correlated Photon Based Absolute Metrology," SUNY, Stony Brook, April 1998.

Miller, C.C., Van Zee, R., Stephenson, J.C., "Mechanism of the Reaction, CH4 + O3 -> CH3 + OH, Studied by Ultrafast Pump/Probe Experiments of the CH4/O3 van der Waals Complex," Gordon Research Conference, Plymouth State College, Plymouth, NH, July 1998.

Ohno, Y., "Color and Photometric Measurement of Displays," DARPA HDS IEC Meeting, Washington, DC, March 1998.

Ohno, Y., "Progress on the Realization of the BIPM Lumen," Seminar at BIPM, Paris, June 1998.

Ohno, Y., "Realization of the NIST Luminous Flux Unit using Absolute Integrating Sphere Method," Seminar at HUT, Helsinki, Finland, July 1998.

Parr, A.C., "History of Light," Franc Grum Memorial Lecture, CORM Annual Meeting, Boulder, CO, May 1998.

Parr, A.C., Datla, R., Saunders, R.D., "Real Time NIST Reference Radiometry using the International Space Station," 27th International Symposium on Remote Sensing of Environment, Tromso, Norway, June 1998.

Parr, A.C., "Improvements in Radiometric and Photometric Measurements at NIST using the High Accuracy Cryogenic Radiometer (HACR)," Optical Society of America Annual Meeting, Baltimore, MD, October 1998.

Rice, Joseph, "Cryogenic Radiometry and Radiometric Transfer Standards," OSA Annual Meeting, Baltimore, MD, October 1998.

Romero, D.B., "Optical Conductivity and Raman Spectroscopy of Manganese Oxides," lecture on Special Problems in Advanced Physics: Properties of Magnetoresistive Oxides Physics Department, University of Maryland, College Park, MD, November 1998.

Romero, D.B., "Raman Spectroscopy of Oxide Perovskite Compounds," MRSEC Seminar, University of Maryland, College Park, MD, April 1998.

Sergienko, A., Muller, A., Migdall, A., and Datla, R., "Polarized Entangled Photons in Quantum Communications and Quantum Metrology," 7th International Workshop on Quantum Optics, Raubichi, Belorussia, May 1998.

Shirley, E.L., "*Ab initio* Calculation of Absorption Spectra with Excitonic Effects," Electronic Exchange and Correlation in Advanced Materials (EXCAM) Workshop on Spectroscopy of Electronic Excitations in Materials, University of Valladolid, Valladolid, Spain, September 1998.

Shirley, E.L., "Efforts Towards Realistic Modeling of Optical Properties," 194th Meeting of the Electrochemical Society, Boston, MA, November 1998.

Shirley, E.L., "X-ray Absorption and Resonant Scattering in s-p Bonded Systems: Some Successes and Some Outstanding Issues," Gordon Research Conference on Electron Spectroscopy, New England College, Henniker, NH, July 1998.

Shirley, E.L., "X-ray Resonant Scattering and Absorption in s-p Bonded Systems," International Workshop on Inelastic X-ray Scattering, Montauk, L.I., NY, October 1998.

IONIZING RADIATION DIVISION (846)

Arif, M., Jacobson, D.L., Greene, G.L., Werner, S.A., Ioffe, A., and Clothier, R.W., "Neutron Interferometry and Optics Facilities at NIST," PECNO Workshop, Prague, Czech Republic, June 1998.

Carlson, A.D., "Current Nuclear Data Activities at NIST," U.S. Nuclear Data Program Meeting, Lawrence Berkeley National Laboratory, Berkeley, CA, March 1998.

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, Antwerp, Belgium, June 1998.

Carlson, A.D., "Status of the Neutron Cross Section Standards," Cross Section Evaluation Working Group, Brookhaven National Laboratory, Upton, NY, October 1998.

Coursey, B.M., "Radiotherapy to Prevent Restenosis," 2nd Annual Conference on Radiation to Prevent Restenosis, LaJolla, CA, January 1998.

Coursey, B.M., "Advances in Cardiovascular Radiation Therapy," Advances in Radiation Therapy II, Washington, DC, March 1998.

Coursey, B.M., "NIST Standards for Intravascular Therapy," American Chemical Society Meeting, Dallas, TX, March 1998.

Coursey, B.M., "Calibration Services in the NIST Ionizing Radiation Division," National Conference of Standardizing Laboratories, Albuquerque, NM, July 1998.

Coursey, B.M. (for Soares, C.S., Coursey, B.M., Seltzer, S.M., Mourtada, F., Mitch, M, Wheatley T., and Norcross, R.), "An Automated Calibration Facility for Brachytherapy Sources," AAPM Meeting, San Antonio, TX, August 1998.

Coursey, B.M., "Madame Curie and the U.S. National Radium Standards," 216th American Chemical Society Meeting, Boston, MA, August 1998.

Desrosiers, M.F., "An Expanded Role for Radiation Metrology," Fifth International Symposium on ESR Dosimetry and Applications, Obninsk, Russia, June 1998.

Desrosiers, M.F., "Technologies for Detection of Radiation Exposure in Bone and Teeth," Genetics in the Courtroom, Eastham, MA, August 1998.

Dewey, M.S. and Kessler, E.G., "Precision Gamma-Ray Measurements,"Applications of Precision Gamma-Ray Spectroscopy Workshop, Notre Dame University, Notre Dame, IN, July 1998.

Gentile, T.R., "Metastability-exchange Optical Pumping of ^{3}He at NIST," Princeton University, Princeton, NJ, April 1998.

Gentile, T.R., "Polarized ^{3}He: Use it to Polarize Neutrons, Image Lungs, Study Neutron Structure–and It's a Floor Wax, Too." Lucent Technologies, Murray Hill, NJ, April 1998.

Huffman, P.R., "Progress Towards Magnetic Trapping of Ultracold Neutrons." International Workshop on Particle Physics with Slow Neutrons, Institut Laue Langevin, Grenoble, France, October 1998.

Ioffe, A., "Electrical Properties of the Neutron," Rhode Island University, Kingston, RI, February 1998.

Ioffe, A., Arif, M., Jacobson, D.L., and Mezei, F., "Precision Neutron Interferometric Search for Evidence of Nuclear Quantum Entanglement in Liquid H_20-D_20 Mixtures," Hahn-Meitner Institut, Berlin, Germany, October 1998.

McLaughlin, W.L., "New Trends in High-Dose Dosimetry," Department of Materials and Nuclear Engineering Seminar, University of Maryland, College Park, MD, May 1998.

McLaughlin, W.L., "An Integrating Photoluminescent Dosimeter Film and Reader System," 10th Tihany Int'l Symp. on Radiation Chemistry, Tata, Hungary, August 1998.

McLaughlin, W.L., "Oscillometric, Fluorimetric, and Photometric Telemetering Techniques for On-line Control in Radiation Processing," 10th Tihany Int'l Symp. on Radiation Chemistry, Tata, Hungary, September 1998.

McLaughlin, W.L., "Electron Beam Radiation Processing," 10th Tihany Int'l Symp. on Radiation Chemistry, Tata, Hungary, September 1998.

McLaughlin, W.L., "Radiation Chemistry of Aqueous Methylene Blue Solutions," 10th Tihany Int'l Symp. on Radiation Chemistry, Tata, Hungary, September 1998.

McLaughlin, W.L., "Light Scattering by Ultrathin Radiochromic Dye Films," 10th Tihany Int'l Symp. on Radiation Chemistry, Tata, Hungary, September 1998.

McLaughlin, W.L., "Radiation Processing Dosimetry–Past, Present and Future," Int'l Symp. on Dosimetry for Radiation Processing in Industry, Agriculture and Medicine, Vienna, Austria, November 1998.

Nico, J.S., "International Collaborations in Physics," American Association for the Advancement of Science and German-American Academic Council Colloquium: U.S. and German Approaches to Int'l Scientific Cooperation, Washington, DC, October 1998.

Seltzer, S.M., "On Interactions of Photons and Electrons," National Institute of Radiological Sciences, Chiba, Japan, August 1998.

Shobe, J., "Absorbed-Dose-To-Water Calibrations at the National Institute of Standards and Technology," AAPM Meeting, San Antonio, TX, August 1998.

Soares, C.G., "Ophthalmic Applicator Calibration and the Issue of Source Uniformity," Meeting of the Nuclear Regulatory Advisory Committee on Medial Uses of Isotopes, Rockville, MD, March 1998.

Soares, C.G., "An Introduction to the Physics of Gamma and Beta Radiation Sources," Advances in Cardiovascular Radiation Therapy, Washington, DC, March 1998.

Soares, C.G., "Standardization of Beta-Particle Reference Radiation Fields Used for Calibration of Extremity Dosimeters," Harshaw/Bicron User's Group Meeting, San Diego, CA, March 1998.

Soares, C.G., "The Great Debate: Gamma vs. Beta Radioisotopes–Gamma Works Better," Transcatheter Cardiovascular Therapeutics X, Washington, DC, October 1998.

Soares, C.G., "Update on New Methods and Isotopes, "Advances in Cardiovascular Radiation Therapy," Washington, DC, March 1998.

Wietfeldt, F.E., "Exploring Time-Reversal Symmetry and Parity Violation with Cold Neutrons," Nuclear Physics Seminar, Institut Laue-Langevin, Grenoble, France, April 1998.

Zimmerman, B.E. and Coursey, B.M., "Standardizations for Radionuclides Used in Bone Palliation Therapy," 215th Meeting of the American Chemical Society, Dallas, TX, March 1998.

Zimmerman, B.E., "The Essentials of Accurate Radioassay in the Clinical Environment," 28th Annual Meeting of the Mid-Eastern Chapter of the Society of Nuclear Medicine, Ocean City, MD, April 1998.

Zimmerman, B.E. and Cessna, J.T., "The Standardization of the Positron-Emitter ^{62}CuPTSM," 216th Meeting of the American Chemical Society, Boston, MA, August 1998.

Zimmerman, B.E. and Cessna, J.T., "Development of a Technique to Determine Experimental Dose Calibrator Settings of Very Short-lived Isotopes: the Standardization of ^{62}CuPTSM," Joint Congress of the European Association of Nuclear Medicine/World Federation of Nuclear Medicine and Biology, Berlin, Germany, September 1998.

TIME AND FREQUENCY DIVISION (847)

Bergquist, J.A., "Metrology and Standards with Laser-Cooled Ions," University of Oregon, Eugene, OR, January 1998.

Bergquist, J.A., "High Accuracy Frequency Standards Using Hg Ions," DAMOP, Santa Fe, NM May 1998.

Bollinger, J.J., "Atomic Ion Crystals in Non-Neutral Plasmas," Conference on Atomic Physics, Windsor, Ontario, Canada, August 1998.

Bollinger, J.J., "Coulomb Crystal Studies of Laser-Cooled Be+ Ions," Conference on Trapped Charged Particles and Fundamental Physics, Monterey, CA, August 1997.

Bollinger, J.J., "Crystalline Order in Laser-Cooled Ion Trap Plasmas," University of Innsbruck, Aarhus, Denmark, October 1998.

Bollinger, J.J., "Crystalline Order in Laser-Cooled, Non-neutral Ion Plasmas", Division of Plasma Physics, APS meeting, New Orleans, LA, November 1998.

Drullinger, R.E., "Report on Joint NIST-CRL Clock," Precision Electronic Measurements Conference, Washington, DC, July 1998.

Evenson, K.M., "Far Infrared Laser Spectroscopy," American Physical Society Conference, University of AZ, Tucson, AZ, March 1998.

Fox, R.W., "High-sensitivity Long Path Spectroscopy," Conference on Applications of Photonic Technology, Ottawa, Canada, July 1998.

Garcia, G., "Narrow Linewidth Phase-lockable High Power DFB Laser," IEEE Conf., Nara, Japan, October 1998.

Hanson, D.W., "Two-way Time Transfer by Telecommunication Satellite; Low-frequency Radio for Time and Frequency Dissemination," Taipei, Taiwan, March 1998.

Hollberg, L., "Laser Sources and Synthesis Technology for Ca," Intl. Workshop on Optical Frequency Measurements, Fremantle, Australia, October 1998.

Itano, W.M., "Quantum Computation with Trapped Ions," Physics Dept. Colloquium, Notre Dame University, South Bend, IN, September 1998.

Itano, W.M., "Crystalline Ion Plasmas," Physics Dept. Colloquium, Argonne National Lab, Chicago, IL, October 1998.

Itano, W.M., "Quantum Computation with Trapped Ions," Physics faculty, Yale University, New Haven, CT, October 1998.

Jefferts, S., "Laser-cooled Atomic Clocks," Battle NW Labs, Richland, WA, December 1998.

King, B.E., "Ground State Cooling of Multiple Trapped Ions," DAMOP, Sante Fe, NM, May 1998.

King, B.E., "Recent Results in Quantum Computation and State Engineering," University of Innsbruck, Innsbruck, Austria, September 1998.

Klappauf, B., "Experiments in Quantum Chaos," NIST Ion Storage Group, Boulder, CO August 1998.

Levine, J., "Fundamentals of Network Time Protocol," NIST Synchronization in Telecommunication Systems Workshop, Eatontown, NJ, April 1998.

Monroe, C., "Quantum Computing with Trapped Ions," SPIE (Division of OSA) Orlando, FL, April 1998.

Monroe, C., "Entanglement of Two Ions," International Conference on Atomic Physics, Windsor, Canada, August 1998.

Monroe, C., "Quantum Computing; Negative Probabilities and Wigner Functions," Univ. of Toronto and Ontario Lightwave Center, Toronto, Canada, March 1998.

Monroe, C., "Quantum Computing," American Physical Society Annual Meeting, Los Angeles, CA, March 1998.

Monroe, C., "Quantum Logic with Trapped Ions," Charged Particles and Fundamental Physics Conference, Monterey, CA September 1998.

Monroe, C., "Quantum Logic with Trapped Ions," Physics Dept., Stanford University, Stanford, CA September 1998.

Monroe, C., "Quantum Computing with Trapped Ions," Physics Dept., University of Indiana, Bloomington, IN, October 1998.

Monroe, C., "Quantum Computing with Trapped Ions," Physics Dept., Rice University, Houston, TX, December 1998.

Nelson, L., "Ion GPS 1998. Report from NIST," Ion-GPS '98. Conference, Nashville, TN, September 1998.

Sullivan, D.B., "Laser-Cooled-Cesium Clock for Applications in Space," Fundamental Physics and Microgravity: 1998. NASA/JPL Workshop, Oxnard, CA, June 1998.

Weiss, M.A., "Cross-Link Paging Potential," GPS performance Analysis Working Group, Colorado Springs, CO, August 1998.

Wineland, D., "Trapped Ions, Schrödinger's Cat, and Quantum Logic," Physics Dept., Purdue University, Lafayette, IN, October 1998.

Wineland, D., "Trapped Ions, Schrödinger's Cat, and Quantum Logic," University of Arizona, Tucson, AZ, October 1998.

Wineland, D., "Trapped Ions, Schrödinger's Cat, and Quantum Computation," Physics Department, Sacramento State University, Sacramento, CA November, 1998.

Wineland, D., "Tests of LLI with Trapped Ions," CPT Workshop, University of Indiana, Bloomington, IN, November 1998.

Wood, C., "New Ideas Concerning Dipole Traps and Optical Cavities," CALTECH, Pasadena, CA, May 1998.

Young, B., "Optical Frequency Standard Using Trapped Hg+ Ions," Trapped Charged Particles and Fundamental Physics '98. Conference, Monterey, CA, September 1998.

QUANTUM PHYSICS DIVISION (848)

Clement, T.S., "Nonlinear Propagation of Femtosecond Pulses in Bulk Media," IEEE Lasers and Electro-Optics Society 1998 Annual Meeting, Orlando, FL, December 1998.

Cornell, E.A., "Experiments in Mixed-Species Bose-Einstein Condensates," Harvard University, Boston, MA, January 1998.

Cornell, E.A., "Three Years of BEC Experiments," University of Florence, Firenze, Italy, February 1998.

Cornell, E.A., "Experiments in Two-Component Condensates," University of Pisa, Pisa, Italy, March 1998.

Cornell, E.A., "BEC: What Have We Learned in Three Years?" University of Milan, Milano, Italy, March 1998.

Cornell, E.A., "Bose-Einstein Condensation," University of Trento, Trento, Italy, March 1998.

Cornell, E.A., "Experiments in Two-Component Condensates," Ecole Normale Superieure, Paris, France, April 1998.

Cornell, E.A., "Experiments in Two-Component BEC," Institute of Theoretical Physics, Santa Barbara, CA, May 1998.

Cornell, E.A., "BEC: Cold New Results," CLEO/IQEC, San Francisco, CA, May 1998.

Cornell, E.A., "Phase Coherent BEC Mixtures," QFS, Amherst, MA, June 1998.

Cornell, E.A., "Experiments in Bose-Einstein Condensation," Enrico Fermi Summer School, Verona, Italy, July 1998.

Cornell, E.A., "BEC Mixtures," University of Texas at Austin, Austin, TX, October 1998.

Cundiff, S.T., "Coherent Phenomena in Semiconductors," Physics and Chemistry Center, Sandia National Laboratories, Albequerque, NM, October 1997.

Faller, J.E., "The Determination of G through the Use of Absolute Gravimetry," 2nd Joint Meeting of the International Gravity Commission and the International Geoid Commission, Trieste, Italy, September 1998.

Faller, J.E., "Precision Measurement with Gravity and Other Things," The University of Vermont, Burlington, Vermont, October 1998.

Faller, J.E., "A New Free-Fall Determination of G," The Gravitational Constant: Theory and Experiment 200 Years after Cavendish, London, England, November 1998.

Faller, J.E., "Precision Measurement with Gravity and Other Things," University of Paris, Paris, France, December 1998.

Faller, J.E., "Precision Measurement with Gravity and Other Things," University of Glasgow, Glasgow, Scotland, December 1998.

Faller, J.E., "Precision Measurement with Gravity and Other Things," University of Konstanz, Konstanz, Germany, December 1998.

Gallagher, A.C., "Particle Growth in Silane Plasmas," Physics of Dusty Plasmas, Boulder, Colorado, April 1998.

Hall, J.L., "Precision Laser Spectroscopy and Optical Frequency Measurements," American Physical Society, Columbus, Ohio, May 1998.

Hall, J.L., "Using Nonlinear Optics to Measure the Optical Frequency of the 532 nm Nd:YAG Laser Stabilized to I_2," CLEO, San Francisco CA, May 1998.

Hall, J.L., "Optical Absorption Sensitivity Better Than $1x10^{-12}$," International Symposium on Molecular Spectroscopy, Columbus, OH, July 1998.

Hall, J.L., "Stabilization and Frequency Measurement of the I_2-stabilized Nd:YAG laser," Conference on Precision Measurement, Washington, DC, July 1998.

Leone, S.R., "Ultrafast Laser Studies of Wave Packet Dynamics," Institute for Atomic and Molecular Science, Taipei, Taiwan, March 1998.

Leone, S.R., "Wave Packet Control with Tailored Femtosecond Pulses," Hebrew University, Jerusalem, April 1998.

Leone, S.R., "Stereochemical Effects in Molecular Dynamics," Weizmann Institute, Rehovot, Israel, April 1998.

Leone, S.R., "Wave Packet Control with Tailored Femtosecond Pulses," Weizmann Institute, Rehovot, Israel, April 1998.

Leone, S.R., "Time-Resolved Near Field Optical Microscopy," Weizmann Institute, Rehovot, Israel, April 1998.

Leone, S.R., "Ultrafast Laser Wave Packet Studies," Tel Aviv University, Tel Aviv, Israel, April 1998.

Leone, S.R., "Amplitude and Phase Control of Rovibronic Wave Packets," 81st Canadian Society for Chemistry Conference, Whistler, British Columbia, Canada, June 1998.

Nesbitt, D.J., "Spectroscopy and Dynamics of Open and Closed Shell Clusters," Gordon Conference on Molecular and Ionic Clusters, Ventura, CA, January 1998.

Nesbitt, D.J., "Clusters, Radicals and Nanostructures," Department of Chemistry, Baylor University, Waco, TX, February 1998.

Nesbitt, D.J., "Clusters, Radicals and Nanostructures," Department of Chemistry, Carroll College, Waukesha, WI, April 1998.

Nesbitt, D.J., "From Clusters to Chemical Reactions: State-Resolved Dynamics via High Resolution IR Laser Methods," Department of Chemistry, UCLA, Los Angeles, CA, March 9, 1998.

Nesbitt, D.J., "Clusters, Radicals and Nanostructures," Department of Chemistry, Marquette University, Milwaukee, WI, April 1998.

Nesbitt, D.J., "Watching Molecules Touch: From IR Laser Studies of Hydrogen Bonding to Atomic Force Microscopy," Department of Chemistry, Carthage College, Milwaukee, WI, April 1998.

Nesbitt, D.J., "Watching Molecules Touch: From IR Laser Studies of Hydrogen Bonding to Atomic Force Microscopy," Department of Chemistry, Beloit College, Beloit, WI, April 1998.

Nesbitt, D.J., "Large Amplitude Vibrational Motion in Hydrocarbon Radicals and H_2-Containing Clusters," workshop on Quantum Dynamics of Coupled Large Amplitude Vibrations in Floppy Molecules, Clusters and Biomacromolecules, Telluride Summer Research Center, Telluride, CO, July 1998.

Nesbitt, D.J., "State-Resolved Dynamics in Water via High Resolution IR Laser Methods: Clusters, Collisions and Photochemistry," International Conference on water in the gas phase, University of Marne-la-Vallee, Paris, France, June 1998.

Nesbitt, D.J., "From Clusters to Chemical Reactions: State-Resolved Dynamics via High Resolution IR Laser Methods," Department of Chemistry, University de Paris-Sud, Orsay, France, June 1998.

Nesbitt, D.J., "State-to-State Collision Dynamics in Crossed Supersonic Jets: Probing Reactions with High Resolution Infrared Lasers," University of Goettingen and Max Planck Institute für Stroemungsforschung, Goettingen, Germany, July 1998.

Nesbitt, D.J., "From Clusters to Chemical Reactions: State-Resolved Dynamics via High Resolution IR Laser Methods," Institute for Theoretical Chemistry, University of Stuttgart, Stuttgart, Germany, June 1998. □

APPENDIX C

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

C

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

LABORATORY OFFICE

Katharine Gebbie

U.S. Member and Vice-President, International Committee for Weights and Measures (CIPM).

President, CIPM Consultative Committee on Temperature.

Member, Executive Committee, Division of Atomic, Molecular, and Optical Physics, American Physical Society.

Member, DoE Fusion Energy Science Advisory Committee and Subpanels on Inertial Fusion Energy and ITER.

Member, ONR Selection Committee for Director of Division of Physical Sciences.

Chair, NSF Panel for Professional Opportunities for Women in Research and Education (POWRE).

Member, APS Task Force on APS Prizes and Awards.

Member, APS Physics Planning Committee.

Member, APS Selection Committee for the Maria Goeppert-Mayer Award.

Chair, the NIST Task Force on Policy for NIST Fellowships.

Member, NIST Centennial Committee.

William R. Ott

NIST Liaison, SDI/BMDO Metrology Projects at NIST.

Member, Program Committee, SPIE Conference on Ultraviolet Atmospheric and Space Remote Sensing: Methods and Instrumentation II, July 1999.

President-Elect, NIST Chapter of Sigma Xi, the Scientific Research Society.

Co-Chairman, NIST Committee on Society-sponsored Centennial Commemorative Events.

Member, Awards Committee, OSTP Presidential Early Career Awards for Scientists and Engineers.

Member, Program Review Committee, Physics Department, St. Joseph's University.

Member, Small Business Innovative Research Selection Committee, helping to select FY98 and FY99 SBIR awards.

Edward B. Saloman

Member, Library Advisory Committee, Optical Society of America.

Barry N. Taylor

Member, Consultative Committee on Units (CCU) of the International Committee for Weights and Measures (CIPM).

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, U.S. National Committee of the International Electrotechnical Commission (IEC) on Technical Committee 25 Matters (TC 25: Quantities and Units and Their Letter Symbols); Member of TC 25 Working Group 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.

NIST Representative, Comptroller, and member of the Executive Committee of the Conference on Precision Electromagnetic Measurements.

NIST Representative to and Chairman of WG 1, Expression of Uncertainty, of the Joint Committee for Guides on Metrology (JCGM).

Barry N. Taylor (continued)

Representative of U.S. National Committee of IEC to the Joint ISO/IEC TAG 4 (TAG 4: Metrology — provides guidance on metrology to the ISO Technical Management Board and the IEC Committee of Action); member, U.S. TAG for ISO/IEC/TAG 4.

Member, JCGM/WG 2, Vocabulary.

Member, joint JCGM/WG 2, ISO/TC 12, IEC/TC 25, and IEC/TC 1 *Ad Hoc* Working Group on the Definitions of Quantities and Units.

Member, Advisory Council of the U.S. Metric Association.

International Union of Pure and Applied Physics (IUPAP) liaison to the IEC.

U.S. representative to IUPAP Commission C2, SUNAMCO (Symbols, Units, Nomenclature, Atomic Masses, and Fundamental Constants).

Member, U.S. National Committee of IUPAP.

Member, Technology Administration Limited Performance Review Board.

Member, American Society for Testing and Materials (ASTM) Committee E-43 on SI Practice, and member, ASTM/IEEE Joint Writing Committee on Metric Practice.

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, Special On-Site Subcommittee for the NIST Centennial.

NIST Expert, Consultative Committee on Electricity and Magnetism (CCEM) of the CIPM.

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Charles W. Clark

Chair, NIST Physics Laboratory Exhibit Committee.

Chair, National Science Foundation Special Emphasis Panel, Rochester Center for Theoretical, Mathematical, and Computational Research in Optical Science and Engineering.

Member, Collaborative Computational Project 2: Continuum States of Atoms and Molecules, Engineering and Physical Sciences Research Council.

Zachary H. Levine

Member, Membership Committee, American Physical Society.

Member, Committee on Committees, American Physical Society.

Member, Committee on Education and Employment Statistics, American Institute of Physics.

Daniel T. Pierce

Vice-Chair, International Advisory Committee, International Colloquium on Magnetic Films Surfaces.

John Unguris

Member, Program Committee for the Magnetism and Magnetic Material Conference.

Member, Program Committee for the American Vacuum Society-Magnetic Interfaces and Nanostructure Group.

ATOMIC PHYSICS DIVISION (842)

Richard D. Deslattes

Member, Technical Program Committee, CPEM 98.

Member at Large of the Section on Physics (B) for the American Association for the Advancement of Science.

Member, *Ad Hoc* Working Group on the Avogadro Constant, Consultative Committee for Mass, International Committee on Weights and Measures.

Member, The Synchrotron Radiation Instrumentation-Cooperative Access Team at Advanced Photon Source, Argonne.

Richard D. Deslattes (continued)

Member, External Advisory Committee, North Carolina Storage Rings for Technology and Applied Research Project.

Jeffrey R. Fuhr

Vice-Chair, Working Group 2: Atomic Transition Probabilities, a subset of Commission 14 (Atomic and Molecular Data) of the International Astronomical Union.

John D. Gillaspy

International Advisory Board, 7th Workshop on Fast Ion-Atom Collisions, Debrecen, Hungary (1998).

Panelist, Department of Energy Review of J.R. Macdonald Laboratory, National User Facility for Atomic Collision Research using highly-charged ions, Physics Department, Kansas State University, November 1997.

Paul S. Julienne

Member, National Research Council Committee on Atomic, Molecular, and Optical Science (CAMOS).

Member of Nominating Committee, Division of Atomic, Molecular, and Optical Physics, American Physical Society.

Yong-Ki Kim

Program Committee, 11th APS Topical Conference on Atomic Processes in Atoms, March 23-26, 1998, Auburn, AL.

Paul D. Lett

Director, NIST Physics Laboratory Summer Undergraduate Research Fellowship program.

Member, National Research Council "Committee on Atomic, Molecular and Optical Sciences" (CAMOS).

William C. Martin

Chairman, Working Group on Atomic Spectra, International Astronomical Union.

Member, Organizing Committee, Commission on Atomic and Molecular Data, International Astronomical Union.

Member, IAEA Network of Atomic Data Centers for Fusion.

Peter J. Mohr

Chairman, Fellowship Committee of the Precision Measurement and Fundamental Constants Topical Group of the APS.

Chairman, CODATA Task Group on Fundamental Constants.

Member, CODATA (Committee on Data for Science and Technology of the International Council of Scientific Unions) Task Group on Fundamental Constants.

Chairman, APS Topical Group, Centennial Display Committee of the Precision Measurement and Fundamental Constants.

Vice-Chairman, Precision Measurement and Fundamental Constants Topical Group of the APS.

Member, Website Task Group, International Conference Series on Atomic and Molecular Data and their Applications.

Member, Executive Board of the Few Body and Multiparticle Dynamics Topical Group of the American Physical Society.

William D. Phillips

Chairman, Division of Laser Science, American Physical Society.

Member, National Academy of Sciences.

Joseph Reader

Member, Program Committee, 6th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, 1998.

Steven L. Rolston

Member, CLEO/QELS 99 Program Committee.

NIST Research Advisory Committee.

NIST Colloquium Committee.

Cha-Mei Tang

Member, IEEE Nuclear and Plasma Science Society, Plasma Science Executive Committee.

Member, IEEE Committee on Women in Engineering.

Member Program Committee, IEEE International Conference on Plasma Science.

Session Chairman, SID Asia Display '98, Seoul, Korea, Sept. 29 to Oct. 1, 1998.

Member, Fellowship Selection Committee, Beams Division, American Physical Society.

Member, Best Ph.D. Thesis Award Committee, Beams Division, American Physical Society (1997-1998).

Wolfgang L. Wiese

Chair, Working Group on Atomic Transition Probabilities, International Astronomical Union.

Co-Chair, 6th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, 1998.

Member, Organizing Committee, International Astronomical Union, Commission on Atomic and Molecular Data.

Member, Network of Atomic Data Centers for Fusion, coordinated by the International Atomic Energy Agency (IAEA).

Member, Program Committee, International Conference on Atomic and Molecular Data and Their Applications, (ICAMDATA).

OPTICAL TECHNOLOGY DIVISION (844)

Yvonne Barnes

Recording Secretary and Member, ASTM-12 Committee, Appearance of Materials, Subcommittees E-12.01 on Editorial and Terminology, E-12.02 on Spectrophotometry and Colorimetry, E-12.04 on Geometric Properties.

Co-Chairperson, E12 *Ad Hoc* Committee on "E12-179."

Member, American Chemical Society (ACS).

Member, Council for Optical Radiation Measurements (CORM).

Member, Inter Society Color Council (ISSC).

Member, Society of Plastic Engineers (SPE).

Sally Bruce

Member of CORM, NCSL, ASQ, and Engineering Technologies Advisory Committee for Montgomery College.

Raju Datla

Member, Space-Based Observations Systems, Committee on Standards, American Institute of Aeronautics, Sensing Systems Working Group, Subcommittee on IR Systems.

Member, SPIE International Technical Working Group on Optical Materials.

Member, ASTM E-13.03, Subcommittee on Infrared Molecular Spectroscopy.

Member, Commission Internationale De L'Eclairage (CIE), USNC.

NIST/Gaithersburg Liaison to the Calibration Coordination Group (DoD/CCG).

Member, CORM IR Optical Properties Subcommittee, OP-5.

Joseph Dehmer

Member, APS Fellowship Committee.

Member, APS Committee on Committees.

Member, Nominating Committee, APS Division of Atomic, Molecular, and Optical Physics.

Member, National Science Foundation Committee of Visitors, Review of AMO Physics Program, Physics Division.

George Eppeldauer

Chairman, CIE TC 2-48 Spectral Responsivity Measurement of Detectors, Radiometers, and Photometers.

Member, CIE TC 2-24 Users Guide for the Selection of Illuminance and Luminance Meters.

Member, CIE TC 2-37 Photometry Using Detectors and Transfer Standards.

Member, CIE TC 2-29 Measurement of Detector Linearity.

Member, CORM (Council on Optical Radiation Measurement).

Member, CORM Subcommittee CR-3 Photometry.

Participant, Revision of E1021 (Standard Test Method for Spectral Response Measurements of Photovoltaic Devices) of the ASTM Subcommittee E44.09.

Joel Fowler

Member, Council for Optical Radiation Measurements.

Charles Gibson

Member, Council for Optical Radiation Measurements (CORM).

Member, American Society for Testing and Materials Committee E20 on Temperature Measurement (ASTM).

Lori Goldner

Chair, American Physical Society Committee on Education.

Jonathan Hardis

Secretary, U.S. National Committee of the CIE.

Chairman, ASTM Subcommittee E12.06 on the Appearance of (Video) Displays.

Member, ASTM Subcommittee E12 Color and Appearance.

Member, CORM Radiometry Subcommittee CR-2.

Member, SEMI FPD Standards Working Group.

Participant, OIDA Roadmapping Activities.

Participant, NEMI Roadmapping Activities.

Leonard Hanssen

Chairman, CORM Optical Properties Subcommittee OP-5, Infrared Optical Properties of Materials.

Member, CORM Optical Properties Subcommittee OP-1 on Geometry.

Member, CIE TC 2-39 Technical Committee on Geometric Tolerance for Colorimetry.

Member, SPIE Working Group on Optical Materials.

Edwin Heilweil

Member, ATP Source Evaluation Board for 1998 "Catalysis and Biocatalysis" focused area competition.

Member, APS 1998 March Meeting organizing committee, Division of Chemical Physics, and attended sorters meeting at AIP headquarters, College Park, MD.

Member, Membership Committee, NIST Sigma XI Chapter.

Vice Chair, 1998 Gordon Conference on "Vibrational Spectroscopy and Molecular Dynamics."

Jon Hougen

Member, Editorial Board of the Journal of Molecular Spectroscopy.

Member, International Advisory Committee for the Ohio State Symposium on Molecular Spectroscopy.

Member, IUPAC Commission on Molecular Structure and Spectroscopy, Subcommittee on Notations and Conventions for Molecular Spectroscopy.

Member, International Advisory Panel (1997-1999) for the Institute of Atomic and Molecular Sciences in Taipei, Taiwan.

Marilyn Jacox

Chairman, Award Recognition Committee, NIST Chapter of Sigma Xi.

B. Carol Johnson

Member, ASTM Subcommittee E20.02 on Radiation Thermometry.

Member, Council of Optical Radiation Measurements.

Member, American Society for Testing and Materials.

Member, NASA/EOS Calibration Panel.

Member, CCT/CCPR Joint Working Group on Thermodynamic Temperature.

Simon G. Kaplan

Member, CORM Subcommittee OP-5 on Infrared Optical Properties of Materials.

Member, SPIE Working Group on Optical Properties of Materials.

Thomas Larason

Member, CIE Technical Committee, TC2-47, Characterization and Calibration Methods of UV Radiometers.

Member, CIE Technical Committee, TC2-48, Spectral Responsivity Measurement of Detectors, Radiometers, and Photometers.

NIST Consultant, Electro-Optical Metrology National Measurement Requirements Committee, National Conference of Standards Laboratories.

Alan L. Migdall

Reviewer, NSF International Research Fellow Awards Program.

Magdalena Navarro

Chair, NIST Diversity Advisory Board, FY98.

Yoshi Ohno

Secretary, CIE Division 2 Physical Measurement of Light and Radiation.

Chairman, CIE TC2-37 Photometry using Detectors as Transfer Standards.

Chairman, CIE TC2-49 Photometry of Flashing Lights.

Chairman, CIE R2-17 Aviation Photometry.

Yoshi Ohno (continued)

Chairman, CORM Subcommittee CR-3 on Photometry.

Member, CCPR Working Group of (λ) Corrected Detectors.

Member, IEC TC100/PT61966 Color Management and Measurement of Multimedia Systems.

Member, IESNA Testing Procedures Committee.

Member, SAE ARP5029 Measurement of Anti-collision Light.

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 Measurement of Detector Linearity.

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 TC2-42 Colorimetry of Displays.

Member, CIE TC2-43 Determination of Measurement Uncertainties in Photometry.

Member, CIE TC2-44 Vocabulary Matters.

Member, CIE TC2-45 Measurement of LEDs, Revision of CIE 127.

Member, CIE TC-46 CIE/ISO Standards on LED Intensity Measurements.

Member, CORM CR4 Integrating Devices.

Delegate to Lamp Testing Engineers Conference (LTEC).

Albert Parr

CIE Division 2 Reporter, "Application of Cryogenic Radiometry."

NIST Representative to CCPR and Member of Subcommittee on UV Standards and Radiometric Lamp Availability.

NIST Representative, CCPR Air UV Working Group.

Ex Officio Member, CORM Board of Directors, NIST Liaison.

Robert Saunders

Member, ANSI Z311, Photobiological Safety of Lamps and Lighting Systems.

Member, CIE TC2-05, Definition and Measurement of Distribution Temperature Measurements.

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.

Ping-Shine Shaw

Member, Review Committee, NASA Ultraviolet, Visible and Gravitational Astrophysics Program for Ultraviolet Supporting Technologies.

Eric Shirley

Member, CORM Subcommittee OP5 on Infrared Optical Properties of Materials.

Member, SPIE Working Group on Optical Properties of Materials.

Member, Washington Editorial Review Board.

Richard Suenram

Member, International Advisory Committee for the Ohio State International Molecular Spectroscopy Symposium.

E. Ambler Thompson

Secretary, CIE Division 6 on Photobiology and Photochemistry.

Member, IES Photobiology Committee.

Member, ASTM E13.06 on Molecular Luminescence.

Member, G-3 on Durability on Nonmetallic Materials.

Benjamin Tsai

Member, ASTM E07 Committee on Nondestructive Testing.

Benjamin Tsai (continued)

Member, ASTM Committee E-21 on Space Simulation and Applications of Space Technology.

Member, ASTM Subommittee E-21.08 on Thermal Protection.

Alfons Weber

Member, ASTM Committee E-13 on Molecular Spectroscopy.

Member, ASTM Committee E-13.03 on Infrared Spectroscopy.

Member, ASTM Committee E-13.06 on Luminescence.

Member, ASTM Committee E-13.08 on Raman Spectroscopy.

IONIZING RADIATION DIVISION (846)

James M. Adams

Member, American Society for Testing and Materials (ASTM) Committee E10 on Nuclear Technology and Applications.

Secretary, ASTM Subcommittee E10.05 on Nuclear Radiation Metrology.

Chairman, ASTM Task Group E10.05.05 on Activation Reactions.

Member, ASTM Symposium Committee, and Program Committee.

Member, American Nuclear Society (ANS) Committee ANS-19.10 on Fast Neutron Fluence to Pressurized Water Reactors.

Member, Council on Ionizing Radiation Measurements and Standards (CIRMS), Subcommittee on Industrial Applications and Materials Effects.

Chairman, Poster Session, Tenth International Symposium on Reactor Dosimetry, Osaka, Japan.

Allan D. Carlson

Member, Cross Section Evaluation Working Group (CSEWG), National Nuclear Data Center.

Member, Evaluation Committee of CSEWG.

Member, Measurements Committee of CSEWG.

Chairman, WPMA Subgroup on the Cross Section Standards.

Member, Working Party on International Nuclear Data Measurement Activities (WPMA) of the Nuclear Energy Agency Nuclear Science Committee (NEANSC).

Coordinator, Subgroup on Evaluation of the Nuclear Data Standards of the Working Party on International Evaluation Cooperation of the NEANSC.

Member, Coordinating Committee of the U.S. Department of Energy (DoE) Nuclear Data Program.

Jeffrey T. Cessna

Member, CIRMS Medical Subcommittee.

Ronald Collé

Member, Interagency Committee on Indoor Air Quality (CIAQ), Radon Workgroup.

Editorial Board, NIST Journal of Research.

Louis Costrell

Chairman, Department of Energy (DoE) National Instrumentation Methods (NIM) Committee.

Chairman, American National Standards Institute (ANSI) Committee N42, Radiation Instrumentation.

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, Organizing Committee, 1999 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

President, International Committee for Radionuclide Metrology (ICRM).

Consultant, Radiation Therapy Committee of American Association of Physicists in Medicine (AAPM).

Delegate, 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, Council on Ionizing Radiation Measurements and Standards (CIRMS).

Member, Board of Visitors, Department of Materials and Nuclear Engineering, University of Maryland-College Park.

Member, Subcommittee on Radiation Research, Committee for Health Safety and Food Research and Development, National Science and Technology Council.

Rapporteur, North American Metrological Organization (NORAMET).

Marc F. Desrosiers

Member, Council on Ionizing Radiation Measurements and Standards (CIRMS), Radiation Effects Subcommittee.

Co-chairperson, American Society for Testing and Materials (ASTM), Committee E10, Alanine Standard subgroup.

Member, ASTM Committee E10, Dosimetry.

Thomas R. Gentile

Member, Magnetism Beam Line Spectrometer Development Team, Los Alamos Neutron Science Center.

David M. Gilliam

NIST Representative, CCEMRI, Section III-Mesures Neutroniques.

Chair, American Society for Testing and Materials (ASTM), Task Group E10.05.10, Neutron Metrology.

Member, ASTM Subcommittee E0.05, Nuclear Radiation Metrology.

Recording Secretary, International Nuclear Target Development Society.

Member, Symposium Committee, ASTM-EURATOM Symposium Committee on Reactor Dosimetry.

Kenneth 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, International Committee for Radionuclide Metrology (ICRM) Scientific Program Committee.

Member, CIRMS Medical Subcommittee.

Paul J. Lamperti

Consultant, AAPM Radiation Committee.

C. Michelle O'Brien

Member, CIRMS Medical Subcommittee.

Member, AAPM TG-2 Subcommittee, Guidelines for Accreditation of Dosimetry Calibration Laboratories in the Calibration of Instruments Used to Measure Radiation Output of Diagnostic X-ray Beams.

Francis J. Schima

Member, International Atomic Energy Agency (IAEA) Coordinated Research Program on Gamma-Ray Standards for Detector Calibration.

Member, ANSI Subcommittee N42.2 Radioactivity Measurements.

Chair, Ionizing Radiation Safety Review Subcommittee, and Member of the NIST Ionizing Radiation Safety Committee.

Member, Washington Editorial Review Board.

Stephen M. Seltzer

Member, International Commission on Radiation Units and Measurements (ICRU).

Member, ICRU Committee on Fundamental Quantities and Units.

Consultant, ICRU Report Committee on Absorbed Dose Standards.

Member, National Council on Radiation Protection and Measurements (NCRP).

Member, NCRP Scientific Committee 86 on Hot Particles in the Eye, Ear or Lung.

Chairman, Joint NCRP/ICRU *Ad Hoc* Committee on Computer Applications.

Consultant, Radiation Therapy Committee Task Group on Kilovoltage X-Ray Beam Dosimetry, American Association of Physicists in Medicine (AAPM).

Member, Secondary Standards Dosimetry Laboratory Scientific Committee, IAEA.

Member, CIRMS Medical Applications.

Member, Technical Committee for the 1998 Nuclear and Space Radiation Effects Conference, Long Beach, CA, July, 1998.

Member, Scientific Committee for the 9th L.H. Gray Conference on Track Structure Simulation in Physical, Chemical and Biological Sciences: Theory and Applications, Oxford, UK, Sept., 1998.

Jileen Shobe

CIRMS Representative, ANSI N13 Parent Committee, Health Physics Society.

Member, Laboratory Accreditation Assessment Committee, Health Physics Society.

Christopher G. Soares

Member, Health Physics Society, Scientific Subcommittee Work Group for the revision of ANSI N545, "Performance, testing, and procedural specifications for thermoluminescence dosimetry (environmental applications)" and the writing of ANSI N13.29, "Criteria for testing environmental dosimetry performance."

Member, Health Physics Society, Scientific Subcommittee Work Group for the revision of ANSI N13.11, "Personnel Dosimetry Performance–Criteria for Testing."

Member, AAPM Committee, Intravascular Brachytherapy Task Group (AAPM/RTC TG60).

Member, AAPM Committee, Radiochromic Film Task Group (AAPM/RTC TG55).

US Technical Expert appointed by ANSI to the International Standards Organization working group (ISO TC 85/2/2), serving on subgroup 0 (beta-particle reference radiations) and subgroup 5 (photon reference radiations).

Member, ICRU Report Committee, "Beta Rays for Therapeutic Applications."

Member, Data Safety Monitoring Committee, Washington Hospital Center.

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, ANSI N42.2, Radioactivity Measurements.

Member, IEEE NIM/FASTBUS Committee.

Member, IEEE Nuclear Instruments and Detectors Committee.

EEO Counselor.

Brian E. Zimmerman

Member, CIRMS Medical Subcommittee.

TIME & FREQUENCY DIVISION (847)

J.C. Bergquist

Member, NSF Review Committee for LIGO (Laser Interferometer for Gravity-Wave Observatory).

Member, NIST Precisions Measurement Grants Committee.

John J. Bollinger

Member, Organizing Committee for the Non-neutral Plasma Workshop.

Member, International Advisory Board, Conference on Strongly Coupled Coulomb Systems.

Member, Executive Committee of the Precision Measurements and Fundamental Constants Topical Group of the American Physical Society.

Robert E. Drullinger

Member, Working Group of the Consultative Committee on Time and Frequency (CCTF) for the Expression of Uncertainties.

D. Wayne Hanson

Member, International Telecommunications Union – Radiocommunications.

Vice Chairman, U.S. Study Group 7, ITU-R; Chairman, U.S. Working Party 7A, ITU-R.

Member, Interference Committee, DoC, Boulder Laboratories.

Leo Hollberg

Chairman, Advance Semiconductor Lasers and Applications, Optical Society of America.

David A. Howe

Member, NIST Research Advisory Committee.

Wayne Itano

Member, Optics Express Development Consortium.

Steve Jefferts

Member, Technical Program Committee, IEEE Frequency Control Symposium.

Member, Technical Program Committee Conference on Precision Electromagnetic Measurements.

Judah Levine

Member, Working Group on International Atomic Time TAI of the CCTF.

Chairman, Working Group on GPS Time Transfer Standards of the CCTF.

Michael Lombardi

Delegate Member, National Conference of Standards Laboratory.

Lisa M. Nelson

Co-Chairman, Civilian GPS Service Interface Committee (CGSIC).

Thomas Parker

Member, Executive Committee for the Annual IEEE International Frequency Control Symposium.

Member, Working Group on Two-Way Time Transfer of the CCTF.

General Chairman, 1998 IEEE International Frequency Control Symposium.

Member, GPS Interagency Advisory Council (GIAC).

Donald B. Sullivan

Chairman, Executive Committee for the Conference on Precision Electromagnetic Measurements (CPEM).

Co-Chairman, Joint Meeting of the IEEE Frequency Control Symposium and the European Frequency and Time Forum.

Member, Consultative Committee on Time and Frequency (CCTF).

Member, Commission A on Time and Frequency, International Telecommunications Union - Radiocommunications Sector.

Member, Executive Committee for the Annual IEEE Frequency Control Symposium.

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 GPS Time Transfer Standards of the CCTF.

Member, Telecommunication Industry Subcommittee on Time and Synchronization.

David J. Wineland

Chairman, Subcommittee on Quantum Optics and Atom Optics, QELS.

Member, National Academy of Sciences.

Member, Committee on Atomic, Molecular, and Optical Science (National Academy of Sciences).

Member, Program Committee, NASA International Conference on Quantum Computing and Quantum Communications.

Member, International Union of Pure and Applied Physics, Commission on Quantum Electronics, 1997-1999.

Member, International Advisory Committee, Conference on Trapped Charged Particles and Fundamental Physics.

Member, Quantum Optics Program Committee, IQEC.

Member, Program Committee, International Conference on Atomic Physics (ICAP-16).

David J. Wineland (continued)

Member, AIP Visiting Scientist Program in Physics.

QUANTUM PHYSICS DIVISION (848)

Eric Cornell

Member, Scientific Committee for Bose-Einstein Condensation 1999 Conference.

James Faller

Member, Directing Board, International Gravity Bureau.

Member, Organizing Committee, 1998 Gravitational Constant Cavendish Conference.

Alan Gallagher

Member, Hydrogenated Amorphous Silicon & Alloys Photovoltaic Development Team, National Energy Renewable Laboratory, DoE.

John Hall

Member, Jet Propulsion Laboratory/NASA Advisory Committee for LISA Space Interferometry Experiment.

Member, Advisory Committee for Laser Spectroscopy Conferences.

Stephen Leone

Councillor, American Physical Society, 1996-1999.

Member, Basic Energy Sciences Advisory Committee, Department of Energy, 1996.

Member, Committee, on Atomic, Molecular, and Optical Sciences (CAMOS).

Chairmam, 4th Generation Light Source Critical Review Panel for the Department of Energy.

Member, Review Panel for the Institute of Atomic and Molecular Science in Taiwan.

David Nesbitt

Member, International Advisory Committee, Molecular Spectroscopy Symposium, Columbus, Ohio (1995-present).

Member, International Organizing Committee, 1998 Conference on Water and Water Clusters, University of Marne-la-Vallee, Paris, France. □

APPENDIX D

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

D

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

LABORATORY OFFICE

W.R. Ott is chairman and organizer of the biweekly "NIST Staff Colloquium Series." There were 22 colloquia in 1998.

ATOMIC PHYSICS DIVISION (842)

G.W. Bryant organized the Division of Material Physics Focused Symposium on "The Optics of Semiconductor Quantum Dots" for the 1999 APS Centennial Meeting.

P.S. Julienne served as co-organizer of the 1999 Gordon Conference on Dynamics of Simple Systems in Chemistry and Physics.

J. Reader organized the semiannual EPRI ALITE Consortium Meeting, NIST, June 11, 1998.

S.L. Rolston sponsored "Atoms, Photons, and Their Interactions" workshop at NIST, June 1998. Approximately sixty participants attended a workshop at NIST held to explore advances in the area of atom-photon interactions. The symposium was in celebration of the awarding of the 1997 Nobel Prize in Physics to W.D. Phillips.

W. Wiese co-chaired the "Sixth International Colloquium on Atomic Spectra and Oscillator Strengths (ASOS 6)," Victoria, British Columbia, Canada. This conference, attended by about 100 scientists from 15 countries, served as a forum to bring together the producers and principal users of atomic spectroscopic data and techniques.

OPTICAL TECHNOLOGY DIVISION (844)

R.U. Datla organized and co-chaired a SPIE conference on "Optical Diagnostic Methods for Inorganic Transmissive Materials" in San Diego, CA, July 1998.

R. Gupta taught an SPIE course entitled "Ultraviolet Source and Detector Radiometry in Semiconductor Production Microlithography" held in Santa Clara on 26th February 1998.

R. Gupta was session chair and member of the organizing committee for a SPIE conference, San Diego, CA, July 19-24,1998.

L.M. Hanssen organized and co-chaired a SPIE conference on "Optical Diagnostic Methods for Inorganic Transmissive Materials," San Diego, CA, July 1998.

C. Johnson, planned and coordinated a "Short Course on Temperature Measurement by Radiation Thermometry," with the support of the Division and ASTM. S. Brown, M. Navarro, and J. Houston were laboratory instructors, NIST, Gaithersburg, MD, June 1-5, 1998.

S.R. Lorentz organized the NIST participation for the 8th Symposium on Infrared Radiometric Sensor Calibration held at Space Dynamics Laboratory, Logan, UT, Sept. 1998.

Y. Ohno, organized and co-chaired Session I, International Radiometry and Photometry Standards of CORM'98 conference held at NIST, Boulder, CO, May 20-22, 1998.

Y. Ohno, planned and coordinated a "NIST Short Course on Photometry," S. Brown and M. Navarro were laboratory instructors, NIST, Gaithersburg, MD, September 10-11, 1998.

IONIZING RADIATION DIVISION (846)

A.D. Carlson organized and chaired a workshop, "A New International Evaluation of the Neutron Cross Section Standards," held at Antwerp, Belgium, June 17, 1998.

K.G.W. Inn and participants of the NIST Radiochemistry Intercomparison Program (NRIP) hosted the "NRIP Workshop and Participants' Meeting" (to address issues for the establishment of a national radiochemistry traceability-testing program). Representatives from the participating laboratories, EPA, DoE National Laboratories, ANSI standards writing committees, the International Atomic Energy Agency (Austria), Ontario Hydro (Canada), and U.S. commercial suppliers of radioactivity standards attended the workshop, March 1998.

C.G. Soares hosted a CIRMS-sponsored workshop on "New Developments in Radiation Protection Dosimetry" on September 25, 1998. More than 40 U.S. and European researchers, personnel dosimetry processors, dosimetry equipment manufacturers and regulatory officials participated in the workshop held at NIST-Gaithersburg to discuss new standards for personnel dosimetry performance testing.

TIME & FREQUENCY DIVISION (847)

D. Howe served as chairman and W. Ortega served as conference organizer for the "Annual Time and Frequency Seminar: Introduction – Level I," June 22-23, 1998, Boulder, CO. This seminar focused on common methods of measuring and interpreting oscillator and clock performance and how these results affect overall system performance.

D. Howe served as chairman and W. Ortega served as conference organizer for the "Annual Time and Frequency Seminar: Fundamentals – Level II," June 24-26, 1998, Boulder, CO. This seminar focused on specialized measurement techniques for quantifying frequency stability and spectral purity of an oscillator.

M. Weiss served as chairman and W. Ortega served as conference organizer for the NIST – Telecom Solutions "Workshop on Synchronization in Telecommunications Systems," held in Boulder, CO, April 20-22, 1998. The workshop offered presentations on current requirements and methods of synchronization in telecommunications systems to beginners and advanced workers in the synchronization field.

S. Jefferts served as facilitator for a workshop sponsored by the Time and Frequency Division on "Satellite-Earth Time Transfer in Support of High-Performance Clocks in Space," October 15-16, 1998, NIST, Boulder , CO.

QUANTUM PHYSICS DIVISION (848)

J.L. Hall organized an international laser intercomparison at JILA from September 15 to October 5, with 2 Russian and 2 French scientists as direct participants.

D.J. Nesbitt served as the main organizer for a workshop sponsored by the National Science Foundation on "Integrating Themes in Physical Chemistry," held in Keystone, CO, Sept 18-20, 1998. This workshop involved facilitating a series of discussions and presentations for roughly 75 leading physical chemists with the director and program managers of the NSF Chemistry Division, in order to develop effective strategies for stimulating and competing for interdisciplinary research funds. ❑

APPENDIX E

JOURNAL EDITORSHIPS

E

JOURNAL EDITORSHIPS

LABORATORY OFFICE

Gebbie, K.B., Editor, *The Gazette*, The American Physical Society Committee on the Status of Women in Physics.

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., Associate Editor, *Optics Express.*

Clark, C.W., Member, Editorial Board, *Journal of Physics B: Atomic, Molecular, and Optical Physics.*

Levine, Z.H., Adjunct Associate Editor, *Physical Review Letters.*

Lucatorto, T.B., Co-editor, *Experimental Methods in the Physical Sciences*, Academic Press Series.

Lucatorto, T.B., Topical Editor for Ultraviolet and X-ray Physics, *Journal of the Optical Society of America, B.*

Pierce, D.T., Advisory Editor, *Journal of Magnetism and Magnetic Materials.*

ATOMIC PHYSICS DIVISION (842)

Deslattes, R.D., Member, Editorial Board, *Physical Review A.*

Deslattes, R.D. Member, International Advisory Board, *Journal of Physics B.*

Kim, Y.-K., Overseas Editor, *Journal of the Korean Physical Society.*

Lett, D.P., Member, Editorial Board *Quantum and Semiclassical Optics*, the Journal of the European Optical Society – B.

Phillips, W., Member, Editorial Board *Advances in Atomic, Molecular, and Optical Physics.*

Reader, J., Editor, "Line Spectra of the Elements," *Handbook of Chemistry and Physics*, CRC Press.

Sansonetti, C., Topical Editor for Atomic Spectroscopy, *Journal of the Optical Society of America B.*

Wiese, W., Associate Editor, *Journal of Quantitative Spectroscopy and Radiative Transfer.*

Wiese, W., Member, Editorial Advisory Board, *Spectrochimica Acta B* (Atomic Spectroscopy), Pergamon Press.

Wiese, W., Member, Editorial Board, "Atomic Data Supplement Series" to *Nuclear Fusion.*

Wiese, W., Member, Editorial Board, "International Bulletin on Atomic and Molecular Data for Fusion," International Atomic Energy Agency.

OPTICAL TECHNOLOGY DIVISION (844)

Hougen, J.T., Member, Editorial Advisory Board, *Journal of Molecular Spectroscopy.*

Johnson, B.C., Edited the *Metrologia* Special Issue to cover the October 1997 NEWRAD meeting.

IONIZING RADIATION DIVISION (846)

Collé, R., Member, Editorial Board, *Journal of Research*, National Institute of Standards and Technology.

Coursey, B.M., Member, Editorial Board, *Applied Radiation and Isotopes.*

Coursey, B.M., Member, Editorial Board, *Nuclear Medicine and Biology.*

Coursey, B.M., Member, Editorial Board, *Radioactivity and Radiochemistry.*

Seltzer, S.M., Member, Editorial Board, *Journal of Physical and Chemical Reference Data.*

Soares, C.G., Member, Editorial Advisory Board, *Vascular Radiotherapy Monitor.*

TIME & FREQUENCY DIVISION (847)

Itano, W.M., Associate Editor, *Optics Express* of the Optical Society of America.

Parker, T.E., Associate Editor, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control.*

Wineland, D.J., Member, Board of Editors, *Review of Scientific Instruments.*

QUANTUM PHYSICS DIVISION (848)

Leone, S.R., Associate Editor, *Annual Reviews of Physical Chemistry.*

Leone, S.R., Advisory Editoral Board, *Chemical Physics Letters*, 1996-1999. □

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.

ATOMIC PHYSICS DIVISION (842)

■ **CRADA with the Advanced Lithography Group.** The EBIT team has renewed a CRADA with the Advanced Lithography Group (ALG), headquartered in Columbia Maryland, in order to continue a valuable interaction with nearby experts working in the field of projection ion lithography. This also opens a channel for possible interaction with Siemens AG in Munich and IMS in Vienna who are leading the world effort in this field now.

■ **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 for development and broad dissemination of a clinically useful method for non-invasively determining 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 applying 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 that 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 of measuring 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 SEMATECH.** The Quantum Metrology Group participates in SEMATECH's efforts on thin film manufacturing and characterization.

■ **CRADA with IBM**. Y.-K. Kim has a CRADA with IBM on the development of multiconfiguration relativistic wave function codes 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 resoucres for a postdoc become available.

■ **Atomic Data for Lighting Research**. The Atomic Spectroscopy Group has entered into a CRADA with the Electric Power Research Institute (EPRI) to implement a research program to produce basic atomic data needed for lighting research. The NIST group is part of an EPRI-led consortium seeking new approaches for high-efficiency commercial lighting that includes the Los Alamos National Laboratory, the University of Wisconsin, Brooklyn Polytechnic Institute, and Osram Sylvania. NIST's part of the research effort is to determine wavelengths and branching ratios in complex spectra using the high-resolution UV/vis/IR Fourier Transform spectrometer and make radiometric measurements of mercury discharges.

OPTICAL TECHNICAL DIVISION (844)

■ **Radiation Thermometry for RTP.** B. Tsai signed a CRADA with Applied Materials (CRADACN-1530) titled "Characterization of the Radiation Environment in RTP Wafer Backside Reflective Type Cavities," and one with Steag AST Elektronik (CRADA CN-1457) titled "Radiation Thermometry for RTP Applications."

■ **NIST/Industry Consortium on Optical Properties of Materials.** Four companies joined the NIST/Industry Consortium on Optical Properties of Materials. They are Hoffman-Rouche, Raytheon, Kodak, and Surface Optics Corporation. The goals of the CRADA are to undertake cooperative research and development on the optical properties of materials leading to standard reference materials and specific calibration services to help the optics industry. The CRADA duration will be 3 years. Alabama A&M University is also considering joining the consortium.

■ **Light Scattering for High Aspect Ratio Via Inspection.** In a CRADA with SEMATECH, Austin, TX, T.A. Germer is developing polarized light scattering techniques to improve the inspection of high aspect ratio vias, the vertical channels that provide contact between one layer and another on patterned semiconductor wafers. The inspection of these vias is critical to the quality assurance of semiconductor devices, but is difficult with light scattering techniques since only small amounts of light reach their bottoms. The use of polarized light is expected to enhance the sensitivity by reducing the noise from other sources of scatter.

IONIZING RADIATION DIVISION (846)

■ **Spectrometric Microdensitometer System for Radiochromic Dose Mapping**. C.G. Soares is working with the Photoelectron Corp, 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.

■ **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 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.

Gel Development for Dosimetry. Under a CRADA with MGS Research, L.R. Karam is working 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 that change color (detectable by tomographic optical scanning) with exposure to radiation and polymer gels that change molecular structure (detectable by NMR spectrometers, clinical magnetic-resonance imagers, spectrophotometers, and tomographic optical scanners). These inexpensive gels offer the possibility of replacing the much more expensive conventional systems with a tissue-equivalent device for dose measurements and the determination of the complete three-dimensional dose distributions. Polymer gels in vessels that meet the requirements of specific experiments are prepared by MGS Research, while radiochromic gels are prepared by NIST; all irradiations are done at NIST.

Ultra Low-Level Radioactivity Detection. This CRADA with BioTraces, Inc. focuses on evaluation of 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. We are supporting the goals of BioTraces by: 1) performing high pressure liquid chromatographic (HPLC) analyses in various biomedical applications (such as ^{125}I labeled plasmid DNA); 2) providing expertise and experimental collaborating on molecular biological applications of the MPD (such as analyses of ^{125}I Western and silver stain blots, ^{32}P labeled DNA, electrophoresis gels, etc. on Fuji system for comparison studies); 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.

Alanine Film Dosimeter for Electron-Beam Processing. In a CRADA with W.R. Grace & Co., Columbia, MD, M.F. Desrosiers is developing a dosimetry system for electron beams based on incorporating alanine detector material into polymer films and a readout method for the film detector using EPR.

TIME & FREQUENCY DIVISION (847)

Frequency Tunable External Cavity Laser Diodes. L. Hollberg is collaborating through a CRADA with Spectra Diode Laboratories, Inc. to develop a high-power, narrow linewidth, frequency-tunable diode laser. The goal of this research project is to develop a frequency-tunable, external-cavity semiconductor laser capable of tuning over 10 nm with a linewidth less than 500 kHz and an output power of 20 mW cw from a single-mode, index-guided laser.

Transfer of GPS Receiver Signal Processing Technology. J. Levine is collaborating under the terms of a CRADA with Hewlett Packard Company to develop an effective software package suitable for making continuous, multi-channel, and common-view time comparisons using the Motorola "ONCORE VP" GPS module.

Alkali-Vapor Atomic Frequency Standards. R.E. Drullinger and F.L. Walls collaborated through a CRADA with Datum, Inc. and Effratom Time and Frequency Products, Inc. to investigate different types of optical pumping and non-optical pumping methods and techniques for use in alkali-vapor atomic frequency standards.

QUANTUM PHYSICS DIVISION (848)

Development of Instrumentation for Ultrafast Optics. S.T. Cundiff has teamed with ThorLabs, Inc. (Newton, NJ) to develop instrumentation for ultrafast optics. Currently the project is focusing on developing compact and inexpensive designs for autocorrelators used to measure the temporal width of ultrafast optical pulses (duration of 100 fs or less).

Frequency Calibrating Optical Spectrum Analyzers. D.J. Nesbitt and S. Gilbert (EEEL) have established a CRADA with Hewlett Packard to develop easily transportable methods for frequency calibrating optical spectrum analyzers using overtone transitions in isotopically labeled $H^{13}CN$ absorption cells.

Synthesizing Isotopically Labeled $H^{13}CN$. D.J. Nesbitt has a CRADA with Environmental Optical Sensors, Inc. to advise them in the technology of synthesizing isotopically labeled $H^{13}CN$ for portable frequency standards and instrument calibration in the 1.5 μ region.

■ **Develop Frequency Stabilization Methods for Diode Lasers.** A CRADA with Focused Research, Santa Clara, CA, is being established to develop frequency stabilization methods for diode lasers. The work is funded as an STTR by NASA and will lead to a stabilized laser operating at 630.5 nm for a space-based oxygen study.

■ **A Small Laser-Interferometric Ballistic Absolute Gravimeter.** J.E. Faller and Micro-g Solutions, the only U.S. firm producing absolute gravimeters commercially, have a CRADA for developing a new, small, laser interferometric, ballistic, 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 proposed new instrument will be much smaller, lighter, and easier for a single person to move about and set up. It should thus be much more attractive as a general research tool and geophysical field instrument. Micro-g Solutions has several ideas for achieving these improvements, which will push the state of the art in nano-metrology and signal processing. Local competence is required to turn these ideas into practical techniques. The proposed CRADA will enable NIST to remain in the forefront of this central aspect of metrology, which can be more generally referred to as ultra precise measurement of acceleration.

OTHER INDUSTRIAL INTERACTIONS

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

■ **Tomographic Reconstruction of an Integrated Circuit Interconnect.** Z.H. Levine conducted joint experiments with Digital Equipment Corporation and Intel Corporation, leading to the first tomographic reconstruction of an integrated circuit interconnect. Using the microfocus capability of the Synchrotron Radiation Instrumentation collaboration of the Advanced Photon Source at Argonne National Laboratory, x-rays at 1.6 keV were passed through the interconnect region of an integrated circuit. The interconnects were digitally reconstructed in three dimensions with 400 nm resolution. Results will appear in January 1999 in Applied Physics Letters.

■ **EUV Optics, Radiometry, and Dosimetry.** T.B. Lucatorto had extended discussions with the EUVL - Limited Liability Corporation about ways in which NIST special expertise can be directed towards supporting the development of Extreme Ultra-Violet Lithography (EUVL). Plans are being developed to perform EUV radiometric measurements and other metrology relevant to the EUVL effort and other new generation lithographic techniques.

ATOMIC PHYSICS DIVISION (842)

■ **Index-of-Refraction Measurement in the VUV.** Though an interaction with MIT Lincoln Laboratories and SEMATECH, we have been making high-accuracy measurements of the index of refraction of calcium fluoride near 157 nm for Silicon Valley Lithography Systems, Inc. We are also measuring its dispersion and temperature dependence. These measurements are needed for the design of lens systems for 157 nm excimer-laser-based photolithographic steppers, which will be used for manufacturing future-generation integrated circuits.

■ **Analysis Software for Near-Field Optical Microscopes.** G.W. Bryant serves as COTR on an SBIR Phase II with Field Precision, Inc. to develop finite element modeling simulation software for near-field scanning optical microscopy.

■ **Optical Computer Aided Tomography for Plasma Uniformity Control.** The plasma radiation group has begun an effort with ATP Intramural funding to develop a plasma uniformity process-control sensor, based on optical computer aided tomography. Measurements of plasma uniformity are of interest to the semiconductor industry and plasma etching tool manufacturers such as LAM Research.

OPTICAL TECHNICAL DIVISION (844)

■ **Low Noise and Flashing Free InSb Radiometers.** G. Eppeldauer developed new low noise and high stability InSb radiometers in conjunction with EG&G Judson. The radiometers measure radiant power or irradiance from 1 μm to 5.4 μm .

■ **Custom made linear preamplifiers**. Analog/Digital Integrated Circuits, Inc., in collaboration with George Eppeldauer, developed preamplifers for small resistance (15 Ω to 20 Ω) and large area (4 mm by 4 mm without any cutline) photoconductive HgCdTe detectors.

■ **Manual on the Use of Radiation Thermometers.** C. Johnson and C. Gibson are using their expertise in temperature measurements and uncertainty analysis to assist the American Society for Testing and Materials (ASTM) Subcommittee E20-02 on Radiation Thermometry. This assistance involves serving as authors, reviewers, and final readers for *the Manual on the Use of Radiation Thermometers* which is under development. This manual provides technical guidance for the practitioner of radiation thermometry.

■ **EOS Radiometry Workshop**. J.P. Rice and B.C. Johnson of NIST participated in the Radiometry Workshop held March 2-4 at the Rosenstiel School of Marine and Atmospheric Science at the University of Miami in Miami, FL. A variety of radiometers and blackbody sources, including a source from NIST, were experimentally intercompared in a laboratory. The main goal was to determine the measurement agreement between various types of radiometers to be used for radiometeric sea surface temperature validations of NASA's Earth Observing System.

■ **SBIR with Cambridge Research and Instrumentation, Inc.** J.P. Rice is a Technical Representative for a DOC Phase I SBIR project with Cambridge Research and Instrumentation (CRI) of Boston, MA. Among other things, this project is developing the High-T_c Space-Based Active Cavity Radiometer (SACR), invented at NIST (see highlight), into a commercial project.

■ **Raman Spectroscopy-Interaction with Industry.** We provided measurements of optical properties of materials for two industrial companies. Dow Chemical requested a Raman characterization to identify certain features of some proprietary materials. Comparisons of the Raman spectra of four different quartz crystals grown under various conditions were made for General Electric.

■ **Infrared Optical Properties of Materials Characterization.** L.M. Hanssen and S.G. Kaplan worked with Raytheon of El Segundo, CA, Northup-Grumman of Baltimore, MD, Aerojet of Azusa, CA, and Aerospace Corporation of Manhattan Beach, CA, to develop accurate infrared seeker systems for Space Based Infrared Systems (SBIRS) Programs, using NIST-calibrated narrow-band filters. The filters were calibrated for both in-band transmittance and out-of-band low-level transmittance. The filters were characterized at the temperature of intended use.

We also worked with Lockheed-Martin of FL to characterize the infrared index of refraction of As_2S_3 for use as a prism spectrometer. The index measurement method employs very high spectral resolution, Fourier transform measurements of etalon samples of the material.

We are working with II-VI Corp., Saxonburg, PA and Ball Aerospace Corp., Boulder, CO to produce high quality and durable mirrors for the Space Infrared Telescope Facility (SIRTF). Measurements of absolute spectral reflectance are performed at NIST on witness samples being developed for the telescope.

■ **Characterizing Conducting Polymer Materials.** We collaborated with the Corporate Processing Technology Center, 3M Company on this research. A co-authored paper on "Near-field Scanning Optical Microscopy of Conducting Phase-separated Polymer Films" will be presented at the MRS spring meeting, 1999.

■ **Calibration of Raytheon Blackbody.** S.R. Lorentz, R.U. Datla, and E. Shirley, calibrated a small aperture cryogenic blackbody for Raytheon – Tucson as part of a Ballistic Missile Defense program.

■ **DNA Hybridization with Far Infrared (THz) Spectroscopy and NSOM.** The Laser Applications Group, with ATP Intramural funding, is studying DNA (and protein) interactions using THz time-resolved spectroscopy. Hybridization and structural changes induced by molecular interactions with water and substrates are of great interest to DNA sequencing companies such as Affymetrix, Genentec, Vysis, and others. J. Hwang also provided NSOM images of silanized glass substrates relevant to understanding DNA probe surface reactions at gene chip surfaces.

■ **FTIR Chemical Imaging.** E.J. Heilweil maintained contact with members of the Small Molecule Pharmaceuticals Group of Amgen, Inc. (Thousand Oaks, CA) to explore methods of rapidly analyzing drugs produced by combinatorial chemistry techniques. Imaging multiple compounds at once and obtaining their IR spectra simultaneously via FTIR-multichannel techniques will greatly speed up identification of undesired or inactive species during molecular synthetic processes. In collaboration with Dr. Carl Zimba of the Polymers Division, interactions with Nicolet and Spectrotech have led to improvements in an FTIR-imaging microscope being developed at NIST.

■ **Mechanistic Data for Zirconocene Catalyst Polymerization Reactions Using Transient Infrared Spectroscopy.** T. Heimer and E. Heilweil of the Laser Applications Group worked with Phillips Petroleum Company on an intramural ATP funded project entitled "Time-resolved Laser Spectroscopy of Catalytic Polymerization Reactions." This study is being pursued to extract laser-initiated polymerization mechanisms of alkenes in solution using generic metallocene catalysts.

■ **Light Scattering from Rough Dielectric Films.** T.A. Germer worked with VLSI Standards, Inc., to develop samples to test theoretical models for polarized light scattering from oxide layers grown on rough silicon wafers. These measurements and models aid the semiconductor industry by providing measurement methodologies that improve the detection and classification of defects and particulate contamination on silicon wafers.

■ **Phillips Petroleum Company.** R.D. Suenram made a series of transient absorbance measurements on several Zirconocene catalysts for the Phillips Petroleum Company as part of an ATP funded project.

■ **On-Line Automotive Emissions Monitor.** R.D. Suenram consulted with Ford Motor Co. through AIGER, the American Industry/ Government Emissions Research consortium, on the development of an on-line, automotive emissions monitor for oxygenated hydrocarbons.

■ **Enhanced Imaging Data Acquisition and Analysis Methods.** E.J. Heilweil is consulting with Talktronics, Inc. Lakeforest, CA on improved data acquisition methods to stream FTIR-Infrared Array images directly into inexpensive PC memory for pre-processing and rapid data analysis.

IONIZING RADIATION DIVISION (846)

■ **High-Power X-ray Tube Development.** C.E. Dick and M.R. McClelland are working with Rayex Corporation to develop a high-power x-ray tube that can be used as a direct replacement for x-ray tubes in medical diagnostic equipment. This tube has the potential of providing higher power or significantly longer life, depending on the modality in which it is used. NIST is helping design the diagnostic tests used to evaluate the device and is providing electronic expertise in maintaining the test equipment.

■ **Dosimetry for Radiation Processing of Particulate and Aerosol Products.** M.F. Desrosiers and S.M. Seltzer are collaborating with researchers from Medpack, Inc., and Trygon, Inc., on the development and refinement of methods for the radiation processing of particulate products carried by air stream through electron beams. Dose measurements in such a difficult environment have been accomplished by the insertion of radiochromic film into the air stream, but the results were suspect due to concerns that the velocity of the films (due to their size and mass) did not replicate that of the product. To better duplicate conditions, alanine powder was used and the doses established by EPR spectrometry. Other efforts in this collaboration involve using Monte Carlo calculations to model other system components and products involved in such processes.

■ **Cryogenic Calorimetry.** We have been working with SRL, Inc., Boston, MA, on a SBIR phase II contract to develop and produce a prototype cryogenic calorimeter. The principle behind this device is that all ionizing radiations will be eventually absorbed by the surrounding matter and converted to heat. This is particularly true for alpha and beta emitters. Clearly, photonic radiations of high energies, typically greater than 50 keV, will not be totally absorbed, or stopped, in a few centimeters of any kind of source containment. Nevertheless, this device should be very useful for the activity assay of most alpha and beta and some isomeric (less than 50 keV) gamma-ray emitting materials.

■ **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.** In collaboration with the Analytical Mass Spectrometry Group, Franklin & Marshall College, and Eastern Analytical Company, we 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 minimal chemical steps performed before measurement.

■ **Standards and Traceability for the Army.** A new traceability program for the U.S. Army was developed, involving the calibration and measurement of swipe samples of various radionuclides to assess the performance of U.S. Army measurement laboratories. Samples of ^{63}Ni were distributed to the participating laboratories.

■ **Semiconductor Neutron Detector.** The Neutron Interactions and Dosimetry Group is working with General Activities, Inc. of Arnold, MD, to develop a new semiconductor neutron detector. The performance and stability of the device will be tested in standard neutron fields.

■ **Intravascular Brachytherapy**. The Radioactivity Group, in collaboration with Interventional Technologies, Inc. and Washington Hospital Center, is developing methods for measuring nuclides used in the prevention of coronary restenosis. Assistance is also being given in the development of synthesis techniques for radiopharmaceuticals used for this purpose. It is hoped that the results of these studies will produce a radiopharmaceutical/ delivery system that shows promise for human trials.

■ **Remote Control of Alanine Dosimeter Measurements**. M.F. Desrosiers is working with Bruker Instruments, Inc., Billerica, MA, to develop hardware and software to control alanine dosimeter measurements remotely. This effort is the basis for the NAMT project being built to offer internet-based radiation calibrations.

■ **Radionuclide Speciation in Soils and Sediments.** This project addresses the identification of radionuclide partitioning in soils and sediments. The approach involves the development of the NIST Standard Extraction Protocol for identifying the fractionation of radioactive elements in soils and sediments. The procedure is designed to partition a soil or sediment sample into six operationally-defined fractions. A methodology was developed to establish the optimum conditions for the first of these six fractions. Reaction time, reagent concentration, and reaction temperatures were chosen as experimental variables. A total of six peer-reviewed publications have resulted from this collaborative project with the Department of Oceanography at Florida State University. In the coming year the collaboration will expand to include researchers from Germany, Ireland, and Norway, who will participate in an intercomparison of the methods developed thus far.

QUANTUM PHYSICS DIVISION (848)

■ **Roughness at Silicon-Silicon Dioxide Interface.** S.T. Cundiff is collaborating with Lucent Technologies, Murray Hill, NJ, on studying the sensitivity of optical second harmonic generation to roughness at the Si/SiO2 interface. This interface is crucial to integrated circuit manufacturers as device sizes shrink. Research in the Quantum Physics Division is concentrating on making second harmonic measurements, while the Lucent researchers are providing samples and characterizing them using x-ray scattering at Brookhaven National Laboratories. Second harmonic generation has the potential to become a metrology tool on integrated circuit fabrication lines .

■ **Optical Science and Engineering Program.** The former "Industry at JILA" program, through which JILA coordinated and broadened its connections to technology-based U.S. companies, has been recently subsumed into the new, multi-department, interdisciplinary, Optical Science and Engineering Program (OSEP). OSEP is a collaboration among JILA, NIST, and the University of Colorado's departments of Physics, Electrical Engineering and Computer Science, and Chemistry and Biochemistry. OSEP is an innovative graduate training program designed to meet the growing demand for individuals with a thorough familiarity with optics in addition to graduate training in Chemistry, Physics, or Electrical and Computer Engineering. The program is built around the "employable quintet" of in-depth technical knowledge, problem solving ability in a laboratory setting, flexibility in learning and working, ability to work in teams, and clarity in oral and written communication. By expanding its connections to include the departments of Electrical and Computer Engineering, and by participating in a new industrial advisory board for OSEP, JILA plans to strengthen and broaden its collaborations with industry while continuing to pursue basic research of exceptional merit and relevance.

■ **DARPA ULTRA Program.** The Quantum Physics Division works with SVT Associates, Minneapolis, MN, under a joint grant from the DARPA ULTRA Program. The joint research explores laser single photon ionization techniques to monitor epitaxial growth. SVT Associates develops commercial instrumentation for flux control in epitaxial growth based on these principles. The methods have recently been applied to nanodot growth mechanisms. ◻

APPENDIX G

OTHER AGENCY RESEARCH AND CONSULTING

G

OTHER AGENCY RESEARCH AND CONSULTING

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

C.W. Clark, developed quantitative models of quantum-degenerate gases for the National Science Foundation, through the University of Maryland.

C.W. Clark, worked on atom-laser design for the Office of Naval Research, in collaboration with the Atomic Physics Division.

M. Furst and R.P. Madden, performed absolute EUV radiometry for NASA to improve the reliability and accuracy of space-borne spectrometers.

D.T. Pierce, R.J. Celotta, and J. Unguris, research for the Office of Naval Research: Investigating magnetism in low-dimensional systems to better understand the magnetic properties of magnetic thin films and multilayers.

J.A. Stroscio, R.J. Celotta, D.T. Pierce, and A.D. Davies, research for the Office of Naval Research: Structure and magnetism of small structures and thin films using scanning tunneling microscopy measurements.

ATOMIC PHYSICS DIVISION (842)

G. Bryant, research for Army Research Laboratory: Modeling and simulation of guide/ anti-guide semiconductor structures to implement self-imaging waveguide beam-splitters.

P. Julienne (with W. Phillips and C.W. Clark), Research for the Office of Naval Research: Experimental and theoretical studies on atom lasers.

Y.-K. Kim, research for DoE: Theory of electron-impact ionization for applications to magnetic fusion.

W. Martin, research for NASA: Critical compilations of atomic spectroscopic data needed for space astrophysics.

W. Martin, research for DoE: Critical compilations of atomic spectroscopic data of magnetic-fusion interest.

W. Phillips, research for the Office of Naval Research: Laser cooling and electromagnetic trapping of neutral atoms.

W. Phillips, research for NASA: Evaporative Cooling of Bose condensates in microgravity.

J. Reader, research for DoE: Spectroscopy of highly ionized atoms to obtain data needed for diagnostics of magnetic-fusion plasmas.

J. Reader and C. Sansonetti, research for NASA: Wavelengths and isotope shifts for Hg II, Zr III, Bi II, Bi III, Pb III.

J. Roberts, research for SEMATECH: Ultraviolet irradiance measurement technology for Deep Ultraviolet photolithography.

W. 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. Martin, and Y.-K. Kim.

W. Wiese, research for NASA: Critical evaluation and compilation of transition-probability data pertinent to the space astronomy program.

W. Wiese, research for NASA: Atomic Oscillator Strength Measurements for the analysis of Hubble Space Telescope data.

OPTICAL TECHNICAL DIVISION (844)

G. Eppeldauer, research for the U.S. Air Force: Develop spatially uniform infrared working standard radiometers for the 5 mm to 20 mm wavelength range.

R. Gupta, measurement of refractive indices for fused silica and calcium fluoride at 193 nm for MIT Lincoln Labs and optical stepper manufacturers.

C. Johnson and F. Lovas, research for U.S. Air Force, CCG: High temperature blackbody calibrator.

C. Johnson and H. Yoon, research for NOAA: Marine optical buoy ocean color program.

C. Johnson, L. Hanssen, and G. Eppeldauer, research for U.S. Air Force, CCG: Rapid blackbody calibrator.

C. Johnson, S. Brown, and H. Yoon, research for NASA: SeaWiFS calibration and validation program.

C. Johnson, S. Brown, T. Larason, research for NASA Landsat Calibration and Validation Program: LXR calibration project.

C. Johnson, Y. Barnes, S. Brown, T. Early, J. Fowler, J. Rice, A. Thompson, and H. Yoon, research for NASA: EOS calibration and validation program.

S.R. Lorentz, T. Jung, A. Carter, C. Morgan, S.G. Kaplan, L.M. Hanssen, and R.U. Datla, research for the BMDO (Air Force): Development of measurement methodologies, calibration services and standards for infrared detectors, blackbodies, and spectral emittance, reflectance and transmittance of materials.

S.R. Lorentz and J.P. Rice, participating in a NASA Phase B study with NRL for the Total Solar Irradiance Monitor (TSIM).

S.R. Lorentz and J.P. Rice, developing an absolute radiometer for the NASA Triana mission.

S.R. Lorentz and J.P. Rice, research for NASA in collaboration with the Naval Research Laboratory on *TASSII: Total and Solar Spectral Irradiance Instrument*: To develop advanced ambient temperature electrical substitution radiometers with which to measure the exo-atmospheric solar constant.

S.R. Lorentz and J.P. Rice, research for NASA with Scripps Institute of Oceanography, GSFC, LANL, Lockheed-Martin, and U. California (San Diego): Develop an electrical substitution radiometer to measure the Earth's reflected and emitted radiation for NASA's Triana mission.

S.R. Lorentz, R.U. Datla and E. Shirley, research for Los Alamos National Laboratory: Calibration of the absolute radiant flux from a large area (10 cm diameter) blackbody that will be used in the calibration of Earth viewing satellites.

S.R. Lorentz and R.U. Datla, research for Ballistic Missile Defense Organization: Low Background IR (LBIR) calibrations.

S.R. Lorentz and R.U. Datla, research for Ballistic Missile Defense Organization: BMDO transfer standard radiometer (BXR) development, calibration and deployment.

S.R. Lorentz and R.U. Datla, research for Ballistic Missile Defense Organization: Infrared detector transfer standards.

S.R. Lorentz and R.U. Datla, research for Ballistic Missile Defense Organization: Improved absolute cryogenic radiometer for the LBIR facility.

F.J. Lovas, research for CCG: Characterized waterbath blackbodies.

Ohno, Y. and Brown, S., research for U.S. Air Force: Display measurements and standards (CCG 422).

E.L. Shirley, research for Ballistic Missile Defense Organization, with Space Dynamics Laboratory, Utah State University: Develop a model for diffraction effects in an infrared calibration chamber used as a source to calibrate infrared radiometric sensors for space applications.

Shaw, P.-S., Visiting scientist at BESSY on UV and x-ray radiometry for PTB, Germany.

IONIZING RADIATION DIVISION (846)

J.M. Adams and D.M. Gilliam, research for Nuclear Regulatory Commission (NRC): Neutron dosimetry measurements and calculations for reactor pressure vessels.

J.M. Adams, principal investigator, research for NRC: Measurement assurance for neutron dosimetry.

A.D. Carlson, research for Department of Energy (DoE): Neutron cross section standards, measurements and evaluations.

J.T. Cessna, research for Environmental Protection Agency (EPA): Perform traceability testing and ongoing review of appropriateness of tests for EPA's primary radon laboratory.

J.T. Cessna, research for EPA: Perform traceability testing of low-level standards from EPA's Environmental Measurements Services Laboratory.

R. Collé, research for EPA: Provide technical assistance to EPA in designing and constructing a pulse-ionization-chamber-based, primary ^{222}Rn calibration system at its Las Vegas Laboratory.

M.S. Dewey, research for DoE: Fundamental physics investigations using cold neutrons.

T.R. Gentile, A.K. Thompson, and G.L. Jones, research for DoE: Develop neutron polarizers based on polarized ^{3}He.

K.G.W. Inn, research for DoE: 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.

K.G.W. Inn and L.L. Lucas, research for DoE's Radiological and Environmental Sciences Laboratory, Idaho Falls: Provide radiochemistry quality assurance to improve the traceability and strengthen the credibility of their Radiobioassay Laboratory Accreditation Program.

L.R. Karam, et al, research for the NEI and the Food and Drug Administration (FDA): Provide standards and calibrations for the primary standards laboratory of the FDA.

L.R. Karam and M.P. Unterweger, research for U.S. Army: Perform traceability testing of U.S. Army primary standards laboratory.

L.R. Karam and M.P. Unterweger, research for U.S. Army: Perform traceability testing of the U.S. Army field testing program such as the calibration and measurement of swipe samples of various radionuclides to assess the performance of U.S. Army measurement laboratories.

L.R. Karam and M.P. Unterweger, research for U.S. Air Force: Provide traceability measurements, and techniques assessments for the U.S. Air Force primary laboratory.

L.L. Lucas and L.R. Karam, research for NRC: Provide traceability testing of the NRC primary quality control laboratory.

J.H. Sparrow, research for U.S. Navy: Provide a measurement assurance program based on national standards to monitor the x-ray outputs of the radiographic, radioscopic, and computed tomographic systems used to nondestructively inspect large solid fuel missiles and associated components.

M.P. Unterweger and L.R. Karam, research for U.S. Air Force: Provide measurements and calculations for beta particles emitted from arbitrarily thick sources plated on substrates of arbitrary atomic number.

J.T. Weaver and J. Shobe, research for U.S. Navy: Fully calibrate ^{137}Cs gamma-ray sources before installation in the Navy personnel dosimetry calibration program.

J.T. Weaver and A.K. Readshaw, research for U.S. Navy: Perform personnel dosimeter irradiations for quality assurance and proficiency testing for the Navy personnel dosimetry calibration program.

TIME & FREQUENCY DIVISION (847)

R.E. Drullinger, consulting with Westinghouse Corporation on a DARPA funded Atomic Clock Project.

R.E. Drullinger, consulting and delivery of a primary frequency standard for Japan's Communications Research 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 for atmospheric and space studies.

D.W. Hanson, consulting to National Weather Service, NOAA: Broadcast of marine weather alerts on WWV and WWVH.

D.W. Hanson, consulting to the US Coast Guard (Dept. Of Transportation): Broadcast of status of GPS satellites on WWV and WWVH.

L.W. Hollberg, research and consulting for the U.S. Army: Acceleration-insensitive low-power clock.

J.A. Levine and 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, US 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.

D.B. Sullivan, research and consulting for NASA: Development of a laser-cooled-cesium clock for scientific and technical applications in space.

F.L. Walls, research for Ft. Monmouth (U.S. Army): Development of phase-noise test sets for PM Milstar project.

F.L. Walls, research and consulting for the Advanced Research Projects Agency: Phase noise support for cesium-cell atomic clock program.

F.L. Walls, research for a security agency: Independent analysis of SMR frequency source.

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 U.S. 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)

T.S. Clement, research for NSF: Research in atomic and molecular physics.

T.S. Clement, research for NSF: Development of a UV-laser based ultrahigh resolution angle-resolved photon.

E.A. Cornell, research for NSF: Research in atomic and molecular physics.

E.A. Cornell, research for ONR: Optical refrigeration in the solid state.

E.A. Cornell, research for ONR: Hollow core fiber atom cooling and couplers.

E.A. Cornell, research for ONR: Neutral atoms, hoses and waveguides.

E.A. Cornell, research for NSF: Alan T. Waterman Award.

S.T. Cundiff, research for NSF: Research in atomic and molecular physics.

S.T. Cundiff, research for Keck Foundation: Keck Optical Measurement Laboratory.

S.T. Cundiff, research for Thorlabs, Inc.: Ultrafast instrumentation development.

J.E. Faller, research for NSF: Development of an active seismic isolation prototype for gravitational wave interferometers.

J.E. Faller, research for NSF: Active seismic isolation for interferometric gravitational wave detectors.

A.C. Gallagher, research for NSF: Research in atomic and molecular physics.

A.C. Gallagher, research for NREL: Amorphous silicon films.

J.L. Hall, research for NSF: Research in atomic and molecular physics.

J.L. Hall, research for NSF/AFOSR: Optical frequency standards and measurement technology.

J.L. Hall, research for CRDF: R&D of laser frequency standards based on the V3 band methane lines and their application for creation of a new grid near IR-visible frequency references.

J.L. Hall, research for NASA: Fundamental physics using frequency-stabilized lasers as optical "atomic clocks".

D.S. Jin, research for NSF: Research in atomic and molecular physics.

S.R. Leone, research NSF/AFOSR: Ion and neural dynamics of ceramic materials formation and atmospheric processes.

S.R. Leone, research for AF/AFOSR: Ion dynamics related to hypersonics.

S.R. Leone, research for ARMY/ARO: Kinetic-energy-enhanced neutral etching.

S.R. Leone, research for ARMY/ARO: Semiconductor processing.

S.R. Leone, research for NSF: Research in atomic and molecular physics.

S.R. Leone, research NSF/AFOSR: State resolved dynamics of ion-molecule collisions in a flowing afterglow.

S.R. Leone, research for DARPA: Ultra sensitive laser ionization technique for real-time analysis control of silicon MBE.

S.R. Leone, research for DoE: Time-resolved FTIR emission studies of laser photofragmentation and radical reactions.

S.R. Leone, research for DURIP: Soft x-ray laser source.

S.R. Leone, research for NASA: Low-temperature rate coefficients relevant to the atmospheric chemistry of the outer planets.

D.J. Nesbitt, research for NASA: Hydroperoxy radical spectroscopy and kinetics relevant to the effects of subsonic aircraft emissions on lower stratosphere ozone.

S.R. Leone, research for NSF: State-resolved molecular dynamics.

D.J. Nesbitt, research for NSF: Research in atomic and molecular physics.

D.J. Nesbitt, research for Outreach: U. Colorado wizard science outreach.

D.J. Nesbitt, research for AFOSR: State-resolved thermal/hyperthermal collision dynamics of atmospheric species.

D.J. Nesbitt, research for NSF: High Resolution IR studies in slit supersonic jets and dynamics of radicals, molecules and clusters. ❑

APPENDIX H

CALIBRATION SERVICES AND STANDARD REFERENCE MATERIALS

H

CALIBRATION SERVICES AND STANDARD REFERENCE MATERIALS

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

CALIBRATION SERVICES PERFORMED

TYPE OF SERVICE	Customer	SP250	No. of Tests	Income
Far UV Detector	University of Firenze Southwest Res. Inst.	40520C	2	6K
Far UV Detector	Smithsonian Observatory John Hopkins University	40531C	2	3.2K
Far UV Detector	Plasmaco, Inc.	40560C	1	9.6K
Far UV Detector	Universal Spectrum Corporation Smithsonian Observatory Johns Hopkins University EMR Photoelectric Lockheed Martin	40561C	5	8K
Far UV Detector	MIT Lincoln Laboratory Leonix Corp. Lockheed Martin Mullard Space Science Lab Osservatorio di Palermo Southwest Research Institute Univ. of California at Berkeley Johns Hopkins University	40599S	10	28.9K

ATOMIC PHYSICS DIVISION (842)

CALIBRATION SERVICES PERFORMED

TYPE OF SERVICE	Customer	No. of Tests	Income
Deuterium lamp calibration	OSRAM Sylvania	1	$ 1,625
Deuterium lamp calibration	KRISS, Republic of Korea	1	$ 1,625
Thin Film Characterization	SEMATECH	16	$25,000

OPTICAL TECHNOLOGY DIVISION (844)

CALIBRATION SERVICES PERFORMED

TYPE OF SERVICE	Customer Classification	SP250	No. of Customers	No. of Tests*	Income
Pyrometer		35010C	17	41	109K
	Industry	through			
	Defense & Aerospace	35070C	6		
	Instrument & Cal labs		4		
	Electrical & Materials		4		
	Government		3		
Spectroradiometry Sources		39010C	19	24	117K
	Industry	through			
	Defense & Aerospace	39060C	5		
	Instrument & Cal labs		4		
	Lighting & Photography		3		
	Government		5		
	University		2		
Spectroradiometry Detectors		39070C	28	76	101K
	Industry	through			
	Defense & Aerospace	39080C	6		
	Instrument & Cal labs		11		
	Lighting & Photography		5		
	Government		4		
	University		2		
Photometry		37010C	20	42	51K
	Industry	through			
	Defense & Aerospace	37180C	9		
	Instrument & Cal labs		4		
	Lighting & Photography		3		
	Government		4		
Spectrophotometry		38010C	20	28	36K
	Industry	through			
	Defense & Aerospace	38100C	4		
	Instrument & Cal labs		12		
	Electrical & Materials		3		
	Government		1		
			104	211	414K

*Number of lamps, detectors, optical filters or reflectors tested.

OPTICAL TECHNOLOGY DIVISION (844) (Con't)

STANDARD REFERENCE MATERIALS

1. **SRM 1001**, X-Ray Step Tablet, for the calibration of optical densitometers and similar equipment using in x-ray fields.
2. **SRM 1008**, Photographic Step Tablet, for the calibration of optical densitometers and similar equipment used in the photographic and graphic arts fields.
3. **SRM 1920a**, Near Infrared Reflectance, for use in calibrating the wavelength scale of reflectance spectrophotometers.
4. **SRM 1921a**, Infrared Transmission Wavelength, for calibrating the wavelength scale of infrared spectometers.
5. **SRM 2003**, First Surface Aluminum on Glass, for specular reflectance from 250 nm to 2500 nm.
6. **SRM 2011**, First Surface Gold Mirror, for specular reflectance from 600 nm to 2500 nm.
7. **SRM 2015**, Opal Glass Reflectance Wafer, for directional-hemispherical reflectance from 400 nm to 750 nm.
8. **SRM 2023**, Second Surface Aluminum Mirror, for specular reflectance from 250 nm to 2500 nm.
9. **SRM 2026**, First Surface Black Glass, for specular reflectance for use in calibrating the photometric scale of specular reflectometers.
10. **SRM 2044**, White Diffuser - Diffuse Spectral Reflectance, for calibrating the reflectance scale of integrating sphere reflectometers.
11. **SRM 2046** through SRM 2051, Infrared Transmission Filters calibrated at 1.06 μm

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Total Spectrophotometric SRMs Distributed: **490**

Gross Sales: $ 55K

IONIZING RADIATION DIVISION (846)

Radiation Interactions and Dosimetry Group

DOSIMETRY OF X RAYS, GAMMA RAYS, AND ELECTRONS

Customer Classification	TYPE OF SERVICE	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial	A	14	56	56,057
	B	4	15	15,473
	C	1	1	2,526
	F	1	4	11,716
Medical Facilities	A	5	5	8,637
	C	1	1	1,200
Government Agencies	A	1	16	18,359
	B	2	3	4,129
Subtotals	A	20	77	83,053
	B	6	18	19,602
	C	2	2	3,726
	F	1	4	11,716
Grand Totals	**ABCF**	**29**	**101**	**118,097**

Service Code	Type of Service	SP250 Numbers
A	X-ray and Gamma-Ray Measuring Instruments	46010C & 46011C
B	Dosimeter Irradiations	46020C & 46021C
C	Tests of Precision Electrometers	46030S
F	Beta-ray Sources and Measuring Instruments	47030C, 47035C, & 47040S

IONIZING RADIATION DIVISION (846) (Cont'd)

Radiation Interactions and Dosimetry Group

HIGH-DOSE CALIBRATION SERVICES PERFORMED

Customer Classification	TYPE OF SERVICE	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial				
Medical product sterilization	A	13	150	62,624
	B	6	16	10,921
	C	1	1	1,767
Industrial				
Electronic hardness testing	A	1	7	2,835
	C	1	1	6,739
Industrial				
Polymer modification	A	2	17	2,125
Subtotals	A	16	174	67,584
	B	6	16	10,921
	C	2	2	8,506
Grand Totals	**ABC**	**24**	**192**	**87,011**

Service Code	Type of Service	SP250 Numbers
A	Irradiate Dosimeters	49010C
B	Supply Transfer Dosimeters	49020C & 49030C
C	Special Measurements	49040S & 49050S

IONIZING RADIATION DIVISION (846) (Cont'd)

Neutron Interactions and Dosimetry Group

DOSIMETRY INSTRUMENT AND SOURCE CALIBRATIONS

Customer Classification	TYPE OF SERVICE	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial				
	H	1	1	2,550
	I	3	3	2,911
Government Agencies				
	H	1	1	2,550
	I	3	5	14,653
Department of Defense	I	1	2	2,500
Subtotals	H	2	2	5,100
	I	7	10	20,064
Grand Totals	**H and I**	**9**	**12**	**25,164**

Service Code	Type of Service	SP250 Numbers
H	Radioactive Neutron Source Calibrations	44010C
I	Neutron Survey Instrument Calibrations	44060C

IONIZING RADIATION DIVISION (846) (Cont'd)

Radioactivity Group

RADIOACTIVITY CALIBRATIONS

Category	Scheduled Calibrations		Non-Scheduled Tests	
	No. of Sources	Income	No. of Sources	Income
Alpha-particle sources	20	21,750	4	5,055
Beta-particle solutions, Gases and solid sources	–	–	11	26,226
Gamma-ray solutions Gases and solid sources	1	1,529	24	20,476
Totals	**21**	**23,279**	**39**	**51,757**

IONIZING RADIATION DIVISION (846) (Cont'd)

Radioactivity Group

STANDARD REFERENCE MATERIALS

RADIOACTIVITY STANDARDS ISSUED

SRM	Radionuclide	Principal Calibration Use
4401L-X	Iodine –131	Activity measurement of radiopharmaceuticals
4404L-U	Thallium –201	"
4407L-V	Iodine –125	"
4410L-X	Technetium –99m	"
4412L-W	Molybdenum –99	"
4415L-V	Xenon –133	"
4416L-S	Gallium –67	"
4417L-R	Indium –111	"
4425L-D	Samarium –153	"
4428L-A	Gadolinium –133	"
4321C	Natural Uranium	Tracer for radionuclide analysis
4324A	Uranium-232	"
4339B	Radium-228	"
4347	Ocean Sediment	Natural Matrix Standard
4906HC	Plutonium-238	Alpha-particle spectrometry
4968	Radon-222 emanation	Radon detector calibration
4990C	Oxalic acid	Carbon-14 dating standard

Total Radioactivity SRMs Distributed: 591

Gross Sales: $345,786

TIME AND FREQUENCY DIVISION (847)

CALIBRATION SERVICES PERFORMED

Note that traceability to NIST and most calibrations are accomplished through direct use reception of NIST broadcasts from WWV, WWVB, WWVH, GOES, and ACTS. In general, for time and frequency metrology, it is only in special situations where in-house calibrations can achieve results not easily obtainable by signal transfer to the user.

FREQUENCY MEASUREMENT SERVICE

This reimbursable service provides measurement assurance for calibration labs. NIST equipment at the user's lab receives LF signals as reference. Performance of user's equipment is monitored through a modem by NIST. An initial setup fee and a monthly fee are charged to the user. The total service income for 1998 was $260,000.

Industrial Users:	30
Government Users:	14

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 lab, analyzes it, and provides a monthly report on the performance of the user's standard. An annual fee is charged to the user. The total service income for 1998 was $52,000.

Industrial Users:	2
Scientific Users:	3
Foreign Users:	2

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APPENDIX I

ACRONYMS

I

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
AI	Associative Ionization
AIAA	American Institute for Aeronautics and Astronautics
AIGER	American Industry Government Emissions Research Consortium
AIP	American Institute of Physics
ALG	Advanced Lithography Group
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
ART	Algebraic Reconstruction Technique
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
BB	Broad-bandwidth
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
BSS	Beta Secondary Standard
BSS.2	Beta-Particle Secondary Standards System
BTI	Bubble Technology, Inc.
BWO	Backward Wave Oscillators
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
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
CCTF	Consultative Committee for Time and Frequency
CDRH	Center for Devices and Radiological Health
CEL	Correlated Emission Laser
CERES	Clouds and Earth's Radiant Energy System
CFS	Constant-Final-State Spectroscopy
CHEM-1	Chemistry
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
CMR	Colossal Magnetoresistance
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
CRADA	Cooperative Research and Development Agreement
CRCPD	Conference of Radiation Control Program Directors
CRI	Cambridge Research Instumentation
CRP	Coordinated Research Program
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
CSIR	Council of Scientific and Industrial Research
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 (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 and 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
EURATOM	European nuclear energy organization
EUROMET	A European collaboration in measurement standards
EUVE	Extreme Ultraviolet Explorer
EXAFS	Edge X-ray Absorption Fine Structure
FAA	Federal Aviation Administration
FACSS	Federation of Analytical Chemistry and Spectroscopy Societies
FAD	FASCAL Accurate Detector
FARCAL	Facility for Advanced Radiometric Calibrations
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
FPC	fullerene production chamber
FT	Fourier Transform
FT-IRAS	Fourier Transform-Infrared Reflection Absorption Spectroscopy
FTIR	Fourier Transform Infrared
FTMS	Fourier Transform Microwave Spectroscopy
FTMW	Fourier-transform Microwave
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
GMR	Giant Magnetoresistance
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
HALO	Hypersonic Aircraft Launch Option
HCCD	mono-deuterated Acetylene
HDR	High Dose Rate
HFIR	High Flux Isotope Reactor
HID	High Intensity Discharge
HIRDLS	High Resolutin Dynamics Limb Sounder
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
HTBB	High-temperature Black Body
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
ICP	Inductively Coupled Plasma
ICPEAC	International Conference on the Physics of Electronic and Atomic Collisions
ICRM	International Committee for Radionuclide Metrology
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
ID	inside diameter
IDMS	Isotope Dilution Mass Spectrometry
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEN	Istituto Elettrotecnico Nazionale (Italy)
IES	Illumination Engineering Society
IESNA	Illumination Engineering Society of North America
IGC	International Gravity Commission
IHPRPTP	Integrated High Payoff Rocket Propulsion Technology Program
ILL	Institut Laue Langevin
ILS	International Laser Spectroscopy
IMECE	International Mechanical Engineering Congress and Exposition
IMGC	Istituto di Metrologia "G. Colonnetti" (Italy)
IMS	Institute for Molecular Science
INDC	International Nuclear Data Committee
INISO-TTC	experimental radiochromic film
INM	Institute National de Metrologie
INMM	Institute for Nuclear Materials Management
INMRI-ENER	Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti--Ente per le Nuove Tecnologie
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
ISS	International Space Station
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
ITL	Information Technology Laboratory
ITS	International Temperature Scale
ITT	Thermal Infrared Transfer Radiometer
ITU	International Telecommunication Union
IU	Indiana University
IUCr	International Union of Crystallography
IUE	International Ultraviolet Explorer
IVBT	intravascular brachytherapy
IVR	Intramolecular Vibrational Relaxation
IVR	Intramolecular Vibrational Redistribution
IWG	Investigators Working Group
JAERI	Japan Atomic Energy Research Institute
JANNAF	Joint-Army-Navy-NASA-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
LAMSCAL	Large Area Monochromatic Source for Calibrations
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
LCIF	Laser-Collision-Induced Fluorescence
LED	Light Emitting Diode
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
LVIS	Low Velocity Intense Source
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
MCT	Mercury-cadmium-telluride
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
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MOT	Magneto Optical Trap
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
NAMT	National Advanced Manufacturing Testbed
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 the 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
NG6	neutron guide no. 6
NG6M	monochromatic beam line near the end of NG6
NGS	National Geological Society
NICE-OHMS	Noise-immune Cavity Enhanced Optical Heterodyne Molecular Spectroscopy
NI&D	Nuclear Interactions and Dosimetry
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.)
NPOESS	National Polar-orbiting Operational Environmental Satellite
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NRIP	NIST Radiochemistry Intercomparison Program
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
NTSB	National Transportation Safety Board
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
OPA	Optical Parametric Amplifier
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
OSL	optical stimulated luminescence
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
PE	performance evaluation
PECVD	Plasma-enhanced Chemical Vapor Deposition
PET	positron emission tomography
PFID	Perturbed Free Induction Decay
PID	Proportional, Integral, and Derivative - a type of servo system
PIXE	Particle Induced X-ray Emission
PL	Physics Laboratory
PMG	Precision Measurement Grant
PMMA	polymethylmethacrylate
PMS	Particle Measurement System
PMT	Photomultiplier Tube
PNL	Pacific Northwest Laboratory
PNNL	Pacific Northwest National Laboratory
POC	Physical Optics Corporation
POP	Plasma Oscillation Probe
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
PT	performance testing
PTB	Physikalisch-Technische Bundesanstalt (Germany)
PTFE	Polytetrafluoroethylene
PUDS	Paired Uranium Detectors
PWR	Pressurized-Water Reactor
PWS	Primary Working Standards
PZT	PiezoElectric Transducer
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
RDP	Rubidium Di-Hydrogen Phosphate
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
SAM's	Self-assembled Monolayers
SACR	Space-based Active Cavity Radiometer
SANS	small-angle neutron scattering

SBIR	Small Business Innovation Research
SCAMPY	Scanning Micro Pyrometer
SCC	Standards Coordinating Committee
SCF	Spectral Comparator Facility
SCLIR	Secondary Calibration Laboratories for Ionizing Radiation
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SDL	Space Dynamics Laboratory
SDL/USU	Space Dynamics Laboratory/ Utah State University
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
SIA	Semiconductor Industry Association
SID	Society for Information Display
SIRCUS	Spectral Irradiance and Radiance Calibration with Uniform Sources
SIRREX-3	SeaWifs Intercalibration Round-robin Experiment
SKACR	Superconducting Kinetic-inductance Absolute Cryogenic Radiometer
SLMs	Synthetic Layer Microstructures
SME	Solar Mesosphere Explorer
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
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
TASSII	Total and Spectral Solar Irradiance Investigation
TC	Technical Committee
TCAP	Time-Correlated Associated Particle
TEPC	Tissue Equivalent Proportional Counter
TEXT	Texas Experimental Tokamak
TFTC	Thin-film Thermocouple
TGM	Toroidal-Grating Monochromator
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
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
VCO	Voltage-Controlled Oscillator
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
WHC	Washington Hospital Center
WHO	World Health Organization
WIPP	Waste Isolation Pilot Plant
WISE	Women in Science and Engineering
WKB	Wentzel-Kramers-Brillouin
WMO	World Metrological Organization
WPMA	working party on measurement activities
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
YAEL	Yankee Atomic Environmental Laboratory
YAG	Yttrium-Aluminum-Garnet
YBCO	Yttriuium-Barium-Cuprate □