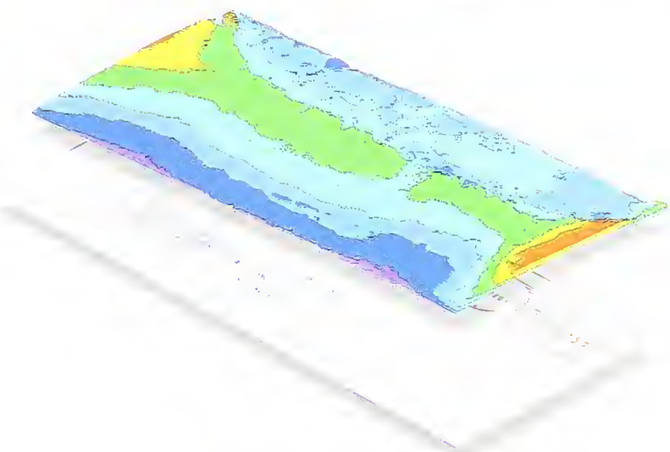
NISTIR 6838

PHYSICS LABORATORY

Annual Report 2001

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



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

NISTIR 6838

PHYSICS LABORATORY
Annual Report 2001

Katharine B.Gebbie, *Director*
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January 2002

U.S. Department of Commerce
Donald L. Evans, Secretary

Technology Administration
Phillip J. Bond, Under Secretary for Technology

National Institute of Standards and Technology
Arden L. Bement, Jr., Director

DESCRIPTION OF COVER ILLUSTRATION

The Physics Laboratory is assisting the U.S. Postal Service in the treatment of mail contaminated with anthrax at postal facilities in Washington, DC (Brentwood) and Trenton, NJ. Working with an interagency task force set up by the Office of Science and Technology, NIST has designed test boxes of mail with NIST reference dosimeters to establish the radiation dose delivered from industrial electron beam facilities. Tests have been carried out at an electron accelerator in Lima, OH and an electron cyclotron in Bridgeport, NJ. NIST measurements, shown here as dose maps with radiochromic film, indicate that the mail is receiving the dose required to inactivate *bacillus anthracis.*

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

DRAFT AGENDA – 12/16/01

Meeting of the Panel for Physics
February 19 – 21, 2002
Boulder, CO

Tuesday, February 19

7:00 p.m.	Reception at the Broker Inn, American Room, Boulder, CO

Wednesday, February 20 – Room GC-402, NOAA Building

8:00 a.m.	Executive Session, including NRC discussion of panel balance and composition (Panel, NRC Staff)	
8:45 a.m.	Welcome and Introductions – Janet Fender, Chair, Panel for Physics	
9:00 a.m.	Director's Welcome and Charge to Panel – Arden Bement, Director, NIST	
9:30 a.m.	Laboratory Overview – Katharine B. Gebbie, Director, Physics Laboratory	
10:25 a.m.	Discussion	
10:45 a.m.	Break	
11:00 a.m.	Physics Laboratory contributions to NIST Strategic Focus Areas:	
	11:00	Nanotechnology – Robert Celotta, NIST Fellow, Leader, Electron Physics Group
	11:30	Quantum Information Program – David Wineland, NIST Fellow, Leader, Ion Storage Group
12:00 noon	Lunch – GB-124, NOAA Building	
	1:00	Health Care – Bert Coursey, Chief, Ionizing Radiation Division
1:30 p.m.	Poster Session	
3:00 p.m.	Laboratory Tours (3 tours for each of 3 groups)	
4:00 p.m.	Executive Session (Panel, NRC staff)	
6:30 p.m.	Cocktails and Dinner – Boulder Cork (*Please place your dinner selection ticket at your seat to aid the wait staff in meal distribution*)	

Thursday, February 21 – Room GC-402, NOAA Building

8:00 a.m.	Executive Session (Panel, NRC staff)
11:00 a.m.	Feedback Session with Laboratory Managers
12:00 noon	Adjourn

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899-
OFFICE OF THE DIRECTOR

NOV 3 0 2001

MEMORANDUM FOR Board on Assessment of NIST Programs and Its Panels

From: Karen H. Brown
Acting Director

Subject: Charge to the National Research Council Board on Assessment of NIST Programs for the FY 2002 Evaluation

I am extremely grateful to the members of the Board on Assessment and its panels for the time, effort, and expertise that all of you devote to evaluating the technical quality of the National Institute of Standards and Technology's (NIST's) laboratory programs. Your findings are a central component of our performance evaluation system and help NIST remain a top-quality science and technology agency serving the nation's measurement needs. NIST highly values your hard work and insights in assessing our laboratory programs, and we look forward to working closely and productively with you in FY 2002.

NIST's mission is to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life. The NIST Laboratories conduct research to anticipate future metrology and standards needs, to enable new scientific and technological advances, and to continuously improve and refine existing measurement methods and services.

For FY 2002, I ask that the Board on Assessment continue your longstanding focus on assessing the technical merit and relevance of NIST's laboratory programs. I also ask the Board to continue your focus on assessing the relevance of NIST work to the needs of our customers, a focus first emphasized last year. Potential demand for NIST measurement and standards will always exceed our limited resources. We ask the Board to continue to help us maximize the impact of our laboratory programs by focusing on the most significant needs of our customers.

In summary, I ask the Board on Assessment to focus its FY 2002 assessment of the NIST Laboratories on four factors:

- the technical merit of the laboratory programs relative to the state-of-the-art worldwide;
- the effectiveness with which the laboratory programs are carried out and the results disseminated to their customers;
- the relevance of the laboratory programs to the needs of their customers; and

NIST

- the ability of the Laboratories' facilities, equipment, and human resources to enable the Laboratories to fulfill their mission and meet their customers' needs.

With its mix of experts from industry, academia, and government agencies, the Board is well positioned to help NIST evaluate its laboratory programs on each of these factors. As in past years, your findings will be valued not only by NIST but also by the Department of Commerce, the Administration, and Congress as they strive to ensure an optimal return on the public's investment in NIST. The Board's reports, statements, and briefings—based on independent and comprehensive expert peer review—are a cornerstone of NIST's performance evaluation system and are featured prominently in our reports to the Administration and Congress under the terms of the Government Performance and Results Act (GPRA). The Board's annual published assessment is a thorough and comprehensive document of great value to NIST and our stakeholders. I would also like to discuss the opportunity for the Board to provide a brief executive summary in addition to the complete assessment to help more broadly disseminate the Board's key findings.

NIST expects that future scientific and technology advances will continue to be more interdisciplinary, including such fields as biosciences and health care, information technology, and nanotechnology. We thank the Board for their insight in experimenting with crosscutting panels to assess some of NIST's interdisciplinary work, including the FY 2001 review of microelectronics programs and the upcoming FY 2002 review of measurement services. We look forward to working closely with the NRC BoA to evaluate the value and effectiveness of these reviews within the context of the overall review process.

The Board can further help NIST's performance evaluation process by tracking over time NIST's responses to the Board's findings and recommendations. Thus I ask the Board to include in your FY 2002 evaluation an assessment of NIST's responses to your FY 2001 report. I look forward to discussing with the Board the possibility of systematically tracking NIST's responses to your findings and recommendations from year to year and over several years in future evaluations.

Thank you again for contributing your time and expertise to assess the quality and relevance of NIST's laboratory programs. Your expert, objective appraisal is crucial to helping NIST continuously improve its programs and effectiveness.

cc: Executive Board
Program Office
Dorothy Zolandz

MESSAGE TO THE PANEL FOR PHYSICS

Katharine B. Gebbie

My colleagues and I join our new Director, Arden Bement, in welcoming you to the Panel for Physics. We recognize the increasing demands on your time and appreciate your willingness to give us your views on the technical merit, relevance and effectiveness of our programs. We value the returning members for the continuity they provide in the assessment process and the new members for their fresh perspectives.

The Laboratory managers wish to thank the returning members for their strong encouragement to articulate an overall strategic vision and goals to convey to our stakeholders the value and effectiveness of our programs. We look forward to hearing your views on our new strategic plan. This plan is consistent with, and supportive of, NIST's 2010 exercise to envision the Institute's future over the next decade, establish long-term strategic goals, and implement a plan for achieving those goals. To this end, NIST is seeking internal input on future opportunities and external input on the future environment for NIST and our stakeholders. On the basis of this input, NIST has refined its mission, vision and core values and is developing a strategic plan to maximize its impact.

STRATEGIC FOCUS

As part of this process, the organizational unit directors have identified six strategic focus areas—areas in which NIST as a whole has the greatest potential to improve its impact on productivity, market access, and public benefit. Of these areas, three are programmatic—nanotechnology, healthcare, and information/knowledge management—and three are organizational—people, customer focus, and information technology infrastructure. Interdisciplinary teams of NIST staff are currently identifying existing programs and resources relevant to each area and developing program and business plans for future resource commitment. Those of you who have already served on the Physics Panel will appreciate that, not surprisingly, many of our programs align well with the NIST strategic focus areas. Yet a meaningful demonstration of impact on the U.S. economy must await the team's definition of the NIST focus within each area.

PROGRAMMATIC BALANCE

In its overall planning process, the Laboratory strives to achieve a balanced portfolio of programs that range from the development and delivery of measurement services to the fundamental research on which the future of these services depends. While we appreciate the recognition afforded our contributions to frontier science, the cost is that we tend to be identified with fundamental research rather than with our world-class services in time and frequency, optical and ionizing radiation, and physical reference data. These services constitute some of NIST's longest-standing and closest ties with industry and the technical community.

At the same time that we are focusing our resources for greater impact, we must be mindful of our responsibility to provide the broad measurement infrastructure capable of responding to diverse and rapidly changing national needs. Just as our knowledge of radiation processing positioned us to lead the interagency effort to sterilize the Nation's mail, so our experience in microwave spectroscopy is allowing us to develop standards for the detection of sarin and other nerve gases. In another area, we are responding to a top priority of the Council for Optical Radiation Measurements with a major effort to improve photometric measurements of LED sources so that the lighting industry may meet its goal of 50 percent market penetration by 2025.

We are pleased to report that, following our success in obtaining competence funding for quantum information in FY2001, our new thrust in biophysics has been funded in FY2002 as part of an interlaboratory effort in single molecule manipulation and measurement. We appreciate the Panel's endorsement of our efforts in both these areas.

I look forward to meeting with you, as schedules allow, at your divisional meetings and to presenting the Laboratory's strategic plan to you at our meeting in February.

INTRODUCTION

SCOPE

This report summarizes the technical programs of the Physics Laboratory for FY 2001 (October 1, 2000 to September 30, 2001). The Laboratory is one of seven major technical units of NIST. It consists of six divisions: Electron and Optical Physics, Atomic Physics, Optical Technology, Ionizing Radiation, Time and Frequency (Boulder), and Quantum Physics (Boulder). Located in the Laboratory office are two cross-cutting programs, the Fundamental Constants Data Center and the Office for Electronic Commerce in Scientific and Engineering Data. The Quantum Physics Division is the NIST component of JILA, a major, cooperative, research program with the University of Colorado.

The Physics Laboratory supports the NIST mission by providing measurement services and research for electronic, optical, and radiation technology. We aim to provide the best possible foundation for measuring optical and ionizing radiation, time and frequency, and fundamental quantum processes. We maintain the U.S. national standards for the Système International (SI) base units of time (the second), light (the candela), and high temperature (above 1200 K). We provide the basis for such SI derived units as the hertz (frequency), the becquerel (radioactivity), and the optical watt and the lumen (light intensity).

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, industrial radiation processing, the environment, health care, transportation, defense, energy, and space.

DELIVERING RESULTS

The strength of NIST in general, and of the Physics Laboratory in particular, is that we are vertically integrated with a balanced portfolio of programs, from those that address the immediate needs of industry, government, and the scientific community, to the more fundamental research that anticipates the Nation's future needs. The Physics Laboratory addresses the fundamental triad of standards, measurement methods, and data in a climate of vigorous and competitive research. Just as the breadth, vigor, and excellence of our research programs provide credibility for our services, so the increasing demands on our services provide the direction and motivation for our research programs.

A good example can be found in our Time and Frequency Division. Here we provide seven different kinds of time and frequency services, ranging from our radio stations, which have spawned a whole new industry in radio controlled clocks, to our Internet Time Service, which receives 250 million hits a day, to our Frequency Measurement and Analysis Service, which is used mainly by major industrial calibration laboratories that serve the highest industrial and governmental demands.

To meet an immediate, challenging, industrial need, we are now working with industry to respond to a DARPA initiative to develop a revolutionary chip-scale atomic clock based on MEMS and VCSEL technologies.

At the same time, we are anticipating the need for still more accurate atomic clocks by working on three, new, primary frequency standards--a cesium fountain standard, a laser-cooled cesium atomic clock for the International Space Station, and an all-optical atomic clock referenced to the 1.064 petahertz transition in a single, laser cooled, trapped mercury ion and a femtosecond, mode-locked, laser frequency comb.

Equally exciting is that the scientists in the Division's ion cooling research group have positioned them as world leaders in the new field of quantum information with their work on trapped, cooled ion frequency standards.

A similar story could be told about our other divisions. For example, the Ionizing Radiation Division is now working with Exxon at the NIST Cold Neutron Research Facility to use the Physics Laboratory's neutron interferometer – the world's most sensitive – to image water in fuel cells. At the same time it is leading interagency initiatives and working with industry on ways to sterilize the mail with electron beam radiation.

The Physics Laboratory is proud that it has some of NIST's longest-standing and closest ties with industry. For example, in optics, we established in 1972 the Council for Optical Radiation

Measurements (CORM) to define pressing problems and projected national needs in radiometry and photometry. It is a non-profit organization composed of individual members from 150 companies, 35 government agencies, and 25 universities interested in measurements of optical radiation including ultraviolet, visible, and infrared. Its aim is to establish a consensus among interested parties on requirements for physical standards, calibration services, and collaborative programs in the field of optical radiation measurements.

In 1992, building on the success of CORM, we formed the Council for Ionization Radiation Measurements and Standards (CIRMS) to advance and disseminate the physical standards needed for the safe and effective application of ionization radiation, including vacuum ultraviolet, x-rays, gamma-rays and energetic particles such as electrons, protons, and neutrons. Technological applications include medical diagnostics and therapy, public and environmental radiation protection, occupational radiation protection, industrial applications and materials effects, medical device sterilization, food irradiation, and, most recently, sterilization of the U.S. mail. This relationship with radiation users, formalized only recently, dates back to the founding of NBS in 1901 and the discovery of the x-ray.

In the case of Time and Frequency services, we determine industrial and national needs by a combination of decadal surveys, responses to phones calls and queries, and contacts with manufacturers of WWWVB clocks and GPS receivers. We are, even now, analyzing the 18,000 responses we have received to our 2001 survey.

Whatever the criteria of success, the Laboratory is among the world's leaders in basic and applied metrology. Our scientists contribute to important practical programs as well as 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.

ORGANIZATION OF REPORT

This report has nine main sections: organization and personnel; program planning and proposals; and seven sections focused on highlights of the year's accomplishments and current and future opportunities for the Laboratory's cross-cutting programs and the six divisions. Following these sections are appendices listing some of our output: publications, talks, collaborations, etc. To obtain more information about particular work, the reader should address the appropriate scientists or the Physics Laboratory office:

Physics Laboratory
National Institute of Standards and Technology
100 Bureau Drive, Stop 8400
Gaithersburg, Maryland 20899-8400
Telephone: 301-975-4200

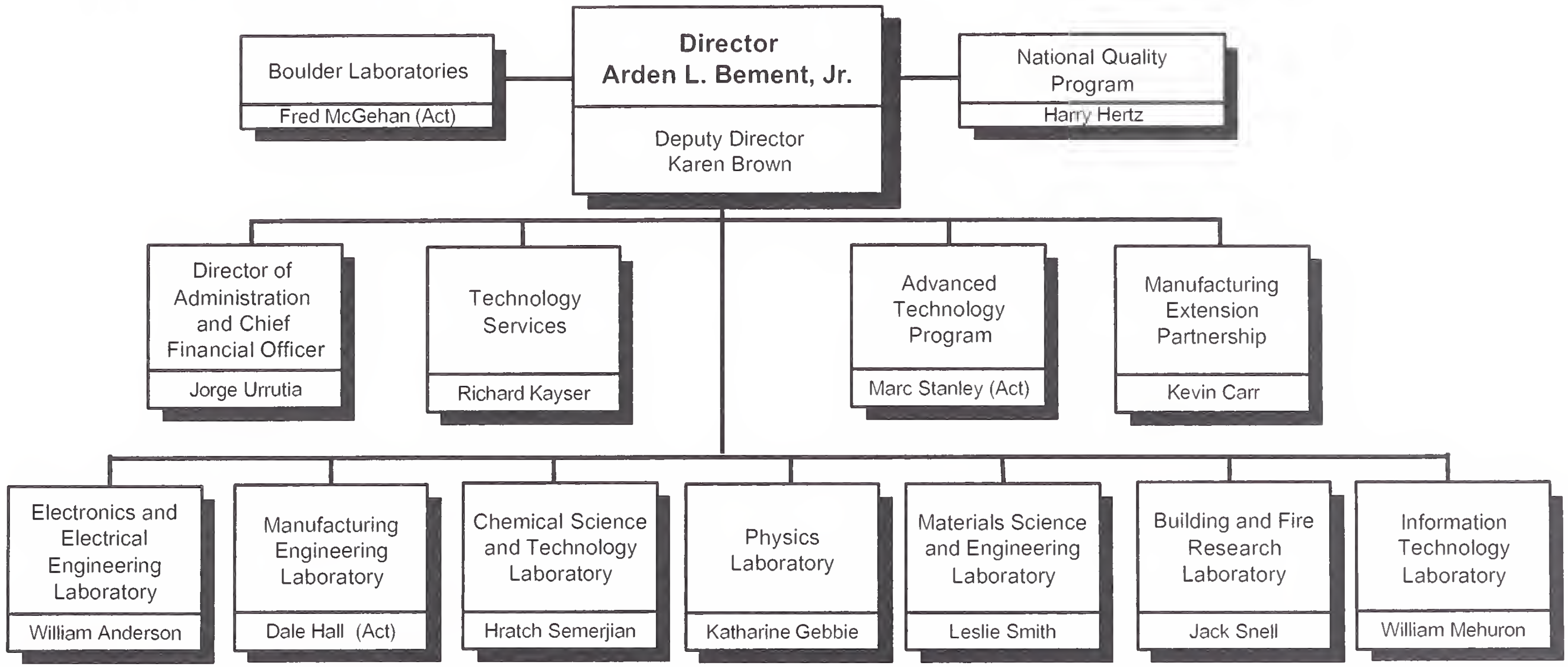
Website: http://physics.nist.gov

Our website includes administrative and technical information, tables of evaluated reference data, research summaries, image galleries, and tutorial materials. One of the most popular websites at NIST with about 700,000 downloads per month, it has won several awards for the quality of its content and presentation. ❑

ORGANIZATION AND PERSONNEL

- Organizational Charts;
- Rosters of Division Staff;
- Summary of Staff by Type of Appointment;
- List of Guest Researchers;
- Functional Statements.

National Institute of Standards and Technology



PHYSICS LABORATORY

Katharine B. Gebbie
Director

William R. Ott
Deputy Director

FUNDAMENTAL CONSTANTS DATA CENTER

Barry N. Taylor, Manager

OFFICE OF ELECTRONIC COMMERCE IN SCIENTIFIC AND ENGINEERING DATA

Robert A. Dragoset, Manager

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

Charles W. Clark, Chief

Photon Physics Group - T. Lucatorto (841.01)
Far UV Physics Group – C.W. Clark (Acting) (841.02)
Electron Physics Group - R. Celotta (841.03)

ATOMIC PHYSICS DIVISION (842)

Wolfgang L. Wiese, Chief

Atomic Spectroscopy Group – J. Reader (842.01)
Quantum Processes Group - P. Julienne (842.02)
Plasma Radiation Group - J. Gillaspy (842.03)
Laser Cooling & Trapping Group - W. Phillips (842.04)
Quantum Metrology Group – E. Kessler (Acting) (842.05)

OPTICAL TECHNOLOGY DIVISION (844)

Albert C. Parr, Chief

Optical Temp. & Source Group – G. Fraser (844.03)
Optical Prop. & Infrared Tech. Group - R. Datla (844.04)
Optical Sensor Group - K. Lykke (844.05)
Laser Applications Group - J. Stephenson, (844.06)
Spectroscopic Applications Group – G. Fraser (844.07)

IONIZING RADIATION DIVISION (846)

Bert M. Coursey, Chief

Radiation Inter. & Dosimetry Group - S. Seltzer (846.02)
Neutron Inter. & Dosimetry Group - D. Gilliam (846.03)
Radioactivity Group – B. Coursey (Acting) (846.04)

TIME AND FREQUENCY DIVISION (847)

Donald B. Sullivan, Chief

Ion Storage Group - D. Wineland (847.10)
Time & Frequency Services Group – J. Lowe (847.40)
Atomic Standards Group - T. Parker (847.50)
Optical Freq. Measurements Group - L. Hollberg (847.80)

QUANTUM PHYSICS DIVISION (848)

James E. Faller, Chief

Fundamental and Precision Measurements
Optical and Nonlinear Optical Physics
Materials Interactions and Characterization
Atomic and Molecular Interactions

PHYSICS LABORATORY OFFICE (840)

Katharine B. Gebbie, Director
A.K. Sweigert, Secretary

William R. Ott, Deputy Director
B. Coalman, Secretary

J. Adams, Scientific Assistant
J. Hardis, Scientific Assistant

J. Beck, Senior Management Advisor and Executive Officer
K. Combs, Administrative Officer (840, 844)
M. Dewese, Administrative Officer (846)
T. Gladhill, Computer Specialist (all Divisions)
K. Haugh, Administrative Officer (841,842)
J. Michael (S)
V. Weedon, Administrative Assistant

FUNDAMENTAL CONSTANTS DATA CENTER (840.01)

(reprogrammed into the Atomic Physics Division)

B. Taylor, Manager
M. Hane, Secretary (1/2)

D. Schwab (S)

OFFICE OF ELECTRONIC COMMERCE IN SCIENTIFIC & ENGINEERING DATA (840.02)

R. Dragoset, Manager
M. Hane, Secretary (1/2)

A. Kishore (S)
K. Olsen
A. Sansonetti (S)
G. Wiersma

(FH) Faculty Hire
(S) Student
(NRC) NRC Postdoctoral Research Associate
(IPA) Intergovernmental Personnel Act

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

C.W. Clark, Chief
H. Felrice, Secretary

J. Chang (S)
M. Edwards (IPA)
W. Reinhardt (FH)
J. Toth (S)
E. Wells (S)
J. Williams (NRC)

PHOTON PHYSICS (.01)

T. Lucatorto, Group Leader
C. Brown, Secretary (1/2)

U. Arp
S. Grantham
Z. Levine
M. Squires (S)
C. Tarrio
R. Vest
E. Wilcox (S)

FAR UV PHYSICS (.02)

C. Clark, Acting Group Leader
C. Brown, Secretary (1/2)

A. Farrell
M. Furst
R. Graves (Deceased)

ELECTRON PHYSICS (.03)

R. Celotta, Group Leader
S. Duvall, Admin. Spt. Asst.

A. Band
R. Biss
S. Blankenship
A. Fein
S. Hill (NRC)
E. Hudson (NRC)
J. Lee
J. McClelland
D. Penn
D. Pierce
C. Sosolik (NRC)
M. Stiles
J. Stroscio
J. Unguris

(FH) Faculty Hire
(S) Student
(NRC) NRC Postdoctoral Research Associate
(IPA) Intergovernmental Personnel Act

ATOMIC PHYSICS DIVISION (842)

W.L. Wiese, Chief
S. Sullivan, Secretary

ATOMIC SPECTROSCOPY

J. Reader, Group Leader
P. Novosel, Secretary (1/2)
B. Whipp, Data Asst/Secretary

J. Curry
W. DeGraffenreid (NRC)
J. Fuhr
Y.-K. Kim
M. Lindsay
P. Mohr
A. Robey
E. Saloman
C. Sansonetti

QUANTUM PROCESSES

P. Julienne, Group Leader
T. Antrobius, Secretary

G. Bryant
E. Bolda (NRC)
J. Burke (NRC)
B. Gao (IPA)
B. Kurtin
E. Tiesinga
C. Williams

PLASMA RADIATION

J. Gillaspy, Group Leader
P. Novosel, Secretary (1/2)

D. Alderson
E. Benck
J. Burnett
T. Moore
L. Ratliff
J. Sanabia (NRC)
G. Vieira (S)

LASER COOLING AND TRAPPING

W. Phillips, Group Leader
M. Fouche, Secretary

K. Emswiler
F. Fatemi (NRC)
S. Gensemer (NRC)
K. Helmerson
K. Jones (IPA)
T. Killian (NRC)
P. Lett
M. Lim (NRC)
L. Lising (NRC)
J. Obrecht
S. Peil
T. Porto
J. Roberts (NRC)
S. Rolston

QUANTUM METROLOGY

E. Kessler, Acting Group Leader
P. Weir, Administrative Assistant

L. Hudson
J. Lawall
R. Matyi
M. Mendenhall (FH)
J.-L. Staudenmann

(FH) Faculty Hire
(S) Student
(NRC) NRC Postdoctoral Research Associate
(IPA) Intergovernmental Personnel Act

OPTICAL TECHNOLOGY DIVISION (844)

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J.E. Hardis, Physicist
R.A. Kuehl, Secretary
V.R. Lenhart, Admin. Support Assistant

OPTICAL TEMPERATURE AND SOURCE

R.D. Saunders, Group Leader
T.V. Pipes, Secretary (1/2)

D.W. Allen
E.D. DeWitt (FH)
E.A.. Early
J.B. Fowler
C.E. Gibson
B.C. Johnson
M.E. Nadal
T.R. O'Brian (detailed to 106)
E. Shen (S)
B.K. Tsai
H.W. Yoon

OPTICAL PROPERTIES AND INFRARED TECHNOLOGY

R.V. Datla, Group Leader
R.C. Lee, Secretary (1/2)

E.K. Chang (NRC)
L.M. Hanssen
S.G. Kaplan
S.R. Lorentz
J.P. Rice
E.L. Shirley

OPTICAL SENSOR

K. Lykke, Group Leader
L.C. Clifford, Secretary

S.W. Brown
S.S. Bruce
E.S. Chu (S)
G.P. Eppeldauer
E.M. Goren (S)
R. Gupta
J.M. Houston
T.C. Larason
C.C. Miller
P.C. Moran (S)
Y. Ohno
P.S. Shaw
D. Shear (S)

LASER APPLICATIONS

J.C. Stephenson, Group Leader
T.V. Pipes, Secretary (1/2)

D. Branning (NRC)
K.A. Briggman
P.M. Connelly
M.J. Fasolka (NRC)
T.A. Germer
S.N. Goldie (NRC)
L.S. Goldner
E.J. Heilweil
W.F. Heinz (NRC)
J. Hwang
L.K. Iwaki (NRC)
B. Thomas (S)
A. Migdall
K. Weston

SPECTROSCOPIC APPLICATIONS

G.T. Fraser, Group Leader
R.C. Lee, Secretary (1/2)

E.A. Dauler
A.R. Hight Walker
J.T. Hougen
D.P. Johnson
J. Lin
M. Litorja
A.L. Migdall
D.F. Plusquellic

(FH) Faculty Hire
(S) Student
(NRC) NRC Postdoctoral Research Associate
(IPA) Intergovernmental Personnel Act

IONIZING RADIATION DIVISION (846)

B.M. Coursey, Chief
S.E. Bogarde, Secretary
L. Costrell, Physicist

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S.M. Seltzer, Group Leader
W.M. Lease, Secretary

F.B. Bateman
P.M. Bergstrom
M.F. Desrosiers
P.J. Lamperti
M.R. McClelland
R. Minniti
M.G. Mitch
C.M. O'Brien
J.M. Puhl
J. Shobe
C.G. Soares
J.H. Sparrow

NEUTRON INTERACTIONS AND DOSIMETRY

D.M. Gilliam, Group Leader
C.R. Chin, Secretary

J.M. Adams
M. Arif
A.D. Carlson
N. Clarkson
M.S. Dewey
T.R. Gentile
P.R. Huffman
D.L. Jacobson
A.K. Komives (NRC)
J.S. Nico
D.R. Rich (NRC)
A.K. Thompson

RADIOACTIVITY

L.R. Karam, Group Leader
A.G. Nimetz, Secretary

J.T. Cessna
R. Collé
P.A. Hodge
K.G.W. Inn
Z.-C. Lin
L.L. Lucas
M.A. Millican
L.S. Pibida
M.P. Unterweger
B.E. Zimmerman

(FH) Faculty Hire
(S) Student
(NRC) NRC Postdoctoral Research Associate
(IPA) Intergovernmental Personnel Act

TIME AND FREQUENCY DIVISION (847)

D. Sullivan, Chief
G. Bennett, Sec. and Editorial Assist.
H. Quartemont, Admin. Officer
K. Belver, Admin. Specialist
S. Kierein, Admin. Assist.
E. Petty, Admin. Assist.

TIME & FREQUENCY SERVICES

J. Lowe, Leader

M. Lombardi
A. Novick

Ft. Collins-WWV

M. Deutch, Chief Engineer

G. Nelson
D. Sutton
B. Yates
J. Folley

Hawaii-WWVH

D. Okayama, Chief Engineer

E. Farrow
D. Patterson
A. Ochinang

NETWORK SYNCHRONIZATION

J. Levine, Project Leader

A. Gifford
L. Nelson

ATOMIC STANDARDS

T. Parker, Leader

J. Gray
T. Heavner
S. Jefferts
T. Peppler
M. Weiss
T. Heavner

ION STORAGE RESEARCH

D. Wineland, Leader

J. Bergquist
J. Bollinger
R. Drullinger
W. Itano
D. Kielpinski
J. Kriesel (NRC)
M. Rowe (NRC)

PHASE NOISE MEASUREMENTS

Vacant, Project Leader

D. Howe
C. Nelson

OPTICAL FREQUENCY MEASUREMENTS

L. Hollberg, Leader

S. Diddams
R. Fox
C. Oates
H. Robinson

(FH) Faculty Hire
(S) Student
(NRC) NRC Postdoctoral Research Associate
(IPA) Intergovernmental Personnel Act

QUANTUM PHYSICS DIVISION (848)

J.E. Faller, Chief
L. Perry, Secretary
W.P. McInerny, Executive Officer
E. Holliness, Supply Officer

C. Frazee, Secretary (JILA)
D. Johnson, Admin.Support (JILA)
B. Horner, Technical Support (JILA)
S. Smith, Safety Officer (JILA)

Fundamental and Precision Measurements

E. Cornell
J.E. Faller
J. Hall
J. Ye

D. Alchenberger (JILA)
P. Beckingham (JILA)
P. Bender (JILA)
L. Chen (JILA)
W.-Y. Cheng (JILA)
N. Djuric (JILA)
G. Dunn (JILA)
K. Holman (JILA)
C. Ishibashi (JILA)
J. Jost (JILA)
H. Lewandowski (JILA)
A. Marian (JILA)
M. Notcutt (JILA)
R. Stebbins (JILA)
A. Vitouchkine (JILA)

Atomic, Molecular, Optical, and Nonlinear Physics

B. Anderson (NRC)
J. Bochinski (NRC)
E. Cornell
S. Cundiff
A. Gallagher
S. Gensemer (NRC)
W. Harper (NRC)
D. Jin
S. Leone
T. Loftus (NRC)
J. McGuirk (NRC)
D. Nesbitt
J. Ye

J. Ames (JILA)
V. Bierbaum (JILA)
J. Bohn (JILA)
J. Briggs (JILA)
I. Christov (JILA)
I. Coddington (JILA)
P. Engels (JILA)
T. Fortier (JILA)
L. Glandorf (JILA)
H. Green (JILA)
P. Haljan (JILA)
S. Han (JILA)
D. Heard (JILA)
E. Hudson (JILA)
S. Inouye (JILA)
W. Jhe (JILA)
S. Johnson (JILA)
T. Kishimoto (JILA)
A. Knight (JILA)
P. Kohl (JILA)
P. Leland (JILA)
L. Lin (JILA)
T. Marcy (JILA)
A. Mulhisen (JILA)
V. Protasenko (JILA)
V. Lorenz (JILA)
J. Peng (JILA)
C. Regal (JILA)
K. Rosza (JILA)
E. Reith (JILA)
D. Samuels (JILA)
J. Shacklette (JILA)
S. Skinner (JILA)
I. Smith (JILA)
M. Smith (JILA)
A. Van Engen (JILA)
Y-J. Wang (JILA)
X. Yang (JILA)
M. Ziemkiewicz (JILA)

Materials Interactions and Characterization

A. Gallagher
S. Leone
D. Nesbitt

Y. An (JILA)
A. Arrowsmith (JILA)
C. Blackledge (JILA)
J. Bohn (JILA)
J. Briggs (JILA)
M. Deskevich (JILA)
T. Haeber (JILA)
D. Havey (JILA)
J. Hodak (JILA)
J. Husband (JILA)
C. Ishibashi (JILA)
B. Liu (JILA)
J. Lucia (JILA)
T. Marcy (JILA)
L. McDonough (JILA)
O. Monti (JILA)
N. Moore (JILA)
J. Preusser (JILA)
H. Stauffer (NRC)
J. Szarko (JILA)
E. Whitney (JILA)

(JILA) Member working with a NIST scientist

(FH) Faculty Hire

(S) Student

(NRC) NRC Postdoctoral Research Associate

(IPA) Intergovernmental Personnel Act

NIST ASSOCIATES

PHYSICS LABORATORY OFFICE

NAMES/DATES	SPONSORS	PROJECT
Dehmer, Patricia 12/1995 to 12/2000	Department of Energy	Atomic, molecular, and optical physical research
Hudson, Ralph 7/1998 to 7/2001	Self	Special issue of NIST J. of Research commemorating 100th anniversary of NIST
King, David 10/2000 to 10/2002	Self	Programmatic thrusts in combinatorial methods and biophysics
Tang, Cha-Mei 5/1999 to 5/2004	Self	Exploration of diverse aspects of x-ray physics
Weber, Alfons 3/1998 to 3/2002	Self	Magneto-Raman spectroscopy of solid state materials

Office of Electronic Commerce in Scientific and Engineering

Baker, Jonathan *10/2000 to 12/2000*	*Self*	*Unix system administration*
Coursey, Johnathan *10/2000 to 1/2001*	*Self*	*Atomic physics database development*
Kotochigova, Svetlana *2/2001 to 11/2001*	*Self*	*Molecular spectroscopy database development*

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NIST ASSOCIATES

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

NAMES/DATES	SPONSORS	PROJECT
Blakie, Peter B. 9/01 to 9/02	University of Otago Dunedin, New Zealand	Modeling and simulation of ultracold atomic gases
Burnett, Keith *7/01 to 6/02*	*Oxford University* *Oxford, UK*	*Optical lattices in quantum computing*
Edwards, Mark 7/01 to 7/02	Georgia Southern University Statesboro, GA	Bose-Einstein condensates
Feder, David 10/01 to 10/02	University of Maryland College Park, MD	Quantum information; computational models for vortice dynamics in BEC
Galbreath, Jacob P. 12/00 to 6/01	Georgia Southern University Statesboro, GA	Development of the NIST Beowulf System
Mahaney, Timothy J. 12/00 to 6/01	Georgia Southern University Statesboro, GA	Development of the NIST Beowulf System
Nygaard, Nicolai 9/99 to 9/02	University of Maryland College Park, MD	Computational models of degenerate Bose and Fermi gases
Pellett, Braden *5/01 to 8/01*	*Harvey Mudd College* *Claremont, CA*	*Quantum communication*
Safronova, Marianna *9/01 to 9/02*	*University of Notre Dame* *South Bend, IN 46556*	*Develop models describing behavior of ultra-cold atoms*
Schneider, Barry 10/92 to 7/02	National Science Foundation Washington, DC	Collaborative research on atomic and molecular theory
Wells, Ed W. 12/00 to 6/01	Georgia Southern University Statesboro, GA	Development of the NIST Beowulf System
Zannoni, Alberto 7/99 to 7/01	University of Maryland College Park, MD	Computational models of Bose and Fermi gases

Photon Physics Group

NAMES/DATES	SPONSORS	PROJECT
Arp, Uwe 12/00 to 8/01	University of Maryland College Park, MD	Establishment of infrared microscope facility at SURF
Baciero, Alfonso 5/01 to 5/02	Laboratorio Nacional de Fusion, CIEMAT, Spain	Study of luminescent materials
Canfield, Randall *5/01 to 5/02*	*Self*	*Development of pulsed EUV radiometry*
Frigo, Sean *7/01 to 7/16/01*	*Nuova Vista* *Las Grange, IL*	*Tomography with scanning transmission electron microscopy*

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NIST ASSOCIATES

ELECTRON AND OPTICAL PHYSICS DIVISION (841) - (Continued)

NAMES/DATES	SPONSORS	PROJECT
Photon Physics Group	(Continued)	
Griesmann, Ulf *6/01 to 12/01*	*Self*	*Design and construction of FTS on Beamline 5*
McCarthy, Kieran 5/01 to 5/02	Laboratorio Nacional de Fusion CIEMAT, Spain	Study of luminescent materials
McNaught, Stuart 8/00 to 7/01	University of Maryland College Park, MD	Pulsed EUV radiometry
Parra, Enrique 6/00 to 5/01	University of Maryland College Park, MD	Pulsed EUV radiometry
Rogers, Raymond *5/01 – 8/01*	*Frostburg State University* *Frostburg, MD*	*Computation of electron mean field paths in electron storage ring*
Spiller, Ebehard *10/00 to 12/00*	*Spiller X-Ray Optics* *Mt. Kisco, NY*	*Matching NIST EUV capabilities to EUV-LLC*
Wilcox, Eva *5/01 to 8/01*	*Brigham Young University* *Salt Lake City, UT*	*EUV Photodiodes*
	Far UV Physics Group	
Deng, Lu *9/01 to 8/02*	*Self*	*EUV Optics and overall system upgrade for calibration beamline at SURF III*
Eparvier, Francis 3/01 to3/02	University of Colorado Boulder, CO	Irradiance calibration of instruments
Fein, Elliott *9/01 to 7/02*	*Self*	*SURF III computerized control system*
Hagley, Edward *11/00 to 10/31-01*	*Self*	*SURF Operations*
Hughey, Lanny 12/00 to 12/01	*Self*	Upgrade of SURF III operations
Mehena, Galila 7/00 to 7/01	Cairo University Giza, Egypt	Synchrotron-based radiometry and optics at SURF III
Ucker, Gregory 3/01 to 3/02	University of Colorado Boulder, CO	Irradiance calibrations for NASA missions
Wen, Jesse *3/01 to 3/02*	*Self*	*Quantum communications*
Woods, Thomas N. 3/01 to 3/02	University of Colorado Boulder, CO	Irradiance calibrations for NASA missions

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ELECTRON AND OPTICAL PHYSICS DIVISION (841) - (Continued)

NAMES/DATES	SPONSORS	PROJECT
Electron Physics Group		
Khalilov, Samed 1/00 to 8/01	University of Technology Dresden, Germany	Develop computer codes to compute electronic structure of materials
Martinez, Yenny *5/01 to 8/01*	*Brigham Young University* *Salt Lake City, Utah*	*Construction of a hollow-cathode-lamp-based laser frequency locking system*
Monchesky, Theodore *9/00 to 3/01*	*Simon Faser University* *Burnaby, BC, Canada*	*Develop procedures for creating high quality epitaxial magnetic films*
Monchesky, Theodore 4/01 to 10/01	Simon Faser University Burnaby, BC, Canada	Develop procedures for creating high quality epitaxial magnetic films

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ATOMIC PHYSICS DIVISION (842)

NAMES/DATES	SPONSORS	PROJECT
Fritzsche, Stephan 11/00 to 12/00	University of Kassel, Kassel, Germany	Atomic structure theory
Barry Taylor 4/01 to 4/02	**Self**	**Fundamental Constants**

Atomic Spectroscopy Group

NAMES/DATES	SPONSORS	PROJECT
Ali, Mahamed Asgar 1/91 to 12/00	Howard University Washington, DC	Transition probabilities calculations
Desclaux, Jean-Paul 4/01 to 5/01	Self	Realativistic atomic structure code
Jentschura, Ulrich 10/96 to 8/01	Technical University Dresden, Germany	Relativistic atomic structure calculations
Kelleher, Dan 4/00 to 10/01	*Self*	*Atomic spectra database*
Martin, William 12/99 to 12/01	**Self**	**Atomic spectroscopic data**
Nave, Gillian 6/94 to 12/01	Harvard College Observatory, Cambridge, MA	Spectral data by Fourier Transform Spectroscopy
Offner, Stella 5/01 to 8/01	Wellesley College Wellesley, MA	Laser spectroscopy of atomic lithium
Podobedova, Larissa 4/97 to 12/01	*Self*	*Evaluation of transition probabilities*
Sansonetti, Jean 11/98 to 10/01	*Self*	*Atomic spectroscopy data*
Stone, Philip 6/96 to 12/01	U.S. Department of Energy Washington, DC	Atomic and molecular collision theory
Tauheed, Ahmad 6/01 to 10/01	Aligarh Muslim University Aligarh, India	Experimental atomic structure
Veza, Damir 7/01 to 9/01	Department of Physics University of Zagreb	Laser spectroscopy

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ATOMIC PHYSICS DIVISION (842) (Continued)

Quantum Processes Group

NAMES/DATES	SPONSORS	PROJECT
Chaumet, Patrick 08/01 to 09/01	Institut Fresnel Marseille France	Coherent control
Falk, Abram 5/01 to 8/01	Swarthmore College Swarthmore, PA	Electron-phonon dynamics in quantum dot quantum wells
Jaskolski, W. 9/01 to 10/01	Nicholas Copernicus University Torun, Poland	Quantum dots
Kotochigova, Svetlana *3/97 to 12/01*	*Self*	*Electronic structure calculations for atom/atom interactions*
Leo, Paul 9/99 to 2/01	University College of London London, England	Cold collisions
Mies, Fred *1/98 to 12/01*	*Self*	*Cold collisions*
Rahmani, Adel 1/99 to 06/02	Universite de Bourgogne Dijon, France	Near-field optics
Sklarz, Shlomo 07/01 to 07/01	Weizmann Institute of Science Rehovot, Israel	Coherent control
Tannor, David 07/01 to 07/01	Weizmann Institute of Science Rehovot, Israel	Coherent control for Quantum Interface
Trippenback, Marek 07/01 to 08/01	University of Warsaw, Warsaw, Poland	Bose-Einstein Condensates
Venturi, Vanessa 06/01 to 05/02	James Cook University Townsville, Australia	Quantum information
Xie, Rui-Hua 09/01 to 09/02	Queen's University Kingston ON, Canada	Nanostructures and nano-optics

Plasma Radiation Group

NAMES/DATES	SPONSORS	PROJECT
Bandler, S. 12/00 to 2/01	Harvard-Smiths. Astrophys. Obs. Cambridge, MA	Electron Beam Ion Trap
Beeler, Matthew 5/01 to 8/01	Miami University Oxford, OH	Plasma process measurement
Berenyi, Zoltan 8/00 to 7/01	Hungarian Academy Science Debrecen, Hungary	Electron Beam Ion Trap

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ATOMIC PHYSICS DIVISION (842) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Plasma Radiation Group (Continued)		
Briand, Jean-Pierre 6/02 to 6/02	University P&M Curie, Paris, France	Electron Beam Ion Trap
Bridges, M. *5/97 to 7/02*	*Self*	*Atomic transition probabilities in a wall stabilized arc source.*
Calamai, Anthony 12/99 to 12/01	Appalachian State Univ. Boone Boone, NC	Electron Beam Ion Trap
Cheng, Hai-Ping 7/98 to 12/01	Dept. Physics, Univ. Florida Gainesville, FL	Molecular dynamics stimulation at the NIST EBIT facility
Defreeze, Frank 7/99 to 7/01	Harvard-Smiths. Astrophys. Obs. Cambridge, MA	Electron Beam Ion Trap
Etemadi, Kasra 1/00 to 12/00	State Univ. New York - Buffalo Buffalo, New York	GEC plasma reference cell
Griesmann, Ulf 4/94 to 3/01	Harvard College Observatory, Cambridge, MA	DUV materials characterization
Kink, Ilmar 8/99 to 12/01	University of Lund, Lund, Sweden	Study of spectra and lifetimes of various highly charged ions using EBIT
Klose, Jules *12/99 to 12/00*	*Self*	*Critical compilations of oscillator strengths for neutral and singly ionized barium*
Knoche, Andreas 9/00 to 2/01	University of Hannover Hannover, Germany	Fourier transform spectrometry
Roberts, Jim 5/00 to 4/01	Self	Electron Beam Ion Trap
Schnopper, Herbert 12/00 to 12/01	Harvard-Smiths. Astrophys. Obs. Cambridge, MA	Electron Beam Ion Trap
Schuch, Reinhold 12/00 to 12/00	Stockholm University, Stockholm, Germany	Electron Beam Ion Trap
Silver, Eric 2/01 to 2/04	Harvard-Smiths. Astrophys. Obs. Cambridge, MA	Electron Beam Ion Trap
Szabo, Csilla 8/00 to 6/01	Kossuth Lajos University Debrecen, Hungary	Electron Beam Ion Trap
Takacs, Endre 4/93 to 5/02	Hungarian Academy of Sciences Debrecen, Hungary	Electron Beam Ion Trap

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ATOMIC PHYSICS DIVISION (842) (Continued)

NAMES/DATES	SPONSORS	PROJECT
	Laser Cooling and Trapping Group	
Araujo, Luis Eduardo 12/00 to 12/02	University of Rochester Rochester, NY	Laser cooling
Boyer, Vincent 4/00 to 8/02	Institut d'Optique Cedex, Paris, France	Laser cooling
Browaeys, Antoine 11/00 to 11/02	Institut d'Optique Paris, France	Laser cooling
Cho, DougHynn 7/00 to 12/00	Korea University Seoul, Korea	Laser cooling
Coelho, Raquel 8/00 to 8/01	Univ. Federal De Pernambuco Pernambuco, Brazil	Laser cooling
Denschlag, Johannes 11/99 to 11/00	University of Innsbruck Innsbruck, Austria	Laser cooling
Diot, Quentin 04/01 to 07/01	Ecole Polytechnique Palaiscau, France	Laser cooling
Dumke, Rainer 9/00 to 3/01	University of Hannover Hannover, Germany	Laser cooling
Laura Feeney 5/01 to 8/01	Miami University Miami, FL	Studies of ultracold plasmas formed from laser-cooled xenon versity
Haeffner, Hartmut 11/00 to 10/01	University of Mainz Mainz, Germany	Laser cooling
Hastings, Sara 5/01 to 8/01	Pomona College Claremont, CA	Micro-assembly with optical forces.
Hensinger, Winfried 04/01 to 08/01	University of Queensland Brisbane, Australia	Laser cooling
Iams, Sarah 5/01 to 8/01	Williams College Williamstown, MA	Photoassociation Spectroscopy
King, Brian 10/99 to 10/02	University of Maryland College Park, MD	Laser cooling
Kishore, Rani *2/94 to 12/01*	*Self*	*Optical tweezers*
Kulander, Kenneth *9/01 to 8/02*	Lawrence Livermore Natl Lab Livermore, CA	Time-dependent dynamics of trapped atoms

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ATOMIC PHYSICS DIVISION (842) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Laser Cooling and Trapping Group (Continued)		
Kulin, Simone-Gunde 11/97 to 5/02	Ecole Normale Superieure Paris, France	Laser cooling
McKenney, Sara 5/01 to 8/01	University of Maryland College Park, Maryland	Micro-assembly with optical forces
McKenzie, Callum 9/00 to 8/02	University of Otago Dunedin, New Zealand	Laser cooling
Millard, Anne 6/01 to 08/01	Ecole Supericure d'Optique Orsay, France	Laser cooling
Upcroft, Benjamin 04/01 to 05/01	University of Queensland Brisbane, Australia	Laser cooling
Quantum Metrology Group		
Campbell, Sarah 5/1 to 8/01	Grinnell College Grinnell, IA	Digital Laue X-Ray Camera
Henins, Albert *7/99 to 7/02*	*Self*	*Crystal and instrument technology*
Lantz, Blandine 6/01 to 8/01	Ecole Superieure d'Optique Orsay, France	Atomic displacement metrology
Marquette, Arnaud 2/01 to 11/01	Centre Universitaire de Paris Orsay, France	Atomic displacement metrology
Owens, Scott 6/99 to 6/02	Goddard Space Flight Center Greenbelt, MD	Multilayer mirror coatings for x-ray coatings
Pedulla, Joe *9/99 to 9/01*	*Self*	*Analysis of thin film and multilayer production and x-ray metrology*
Prudnikov, Ilya 7/00 to 8/01	Lomonosov Moscow State Univ. Moscow, Russia	Advanced modeling of x-ray scattering by thin films

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OPTICAL TECHNOLOGY DIVISION (844)

NAMES/DATES	SPONSORS	PROJECT
	Optical Temperature and Source Group	
Allen, David *10/09 to 5/01*	*Self*	*Electrical wiring system of Medium Background Infrared Chamber*
Andor, Gyorgy 8/01 to 11/01	Hungarian Natl Office of Measures Nemetrologyi, Hungary	Develop new state-of-the-art colorimetry to measure color samples
Annageri, Murthy *2/95 to 12/03*	*Aerotech, Inc* *Hampton, VA*	*Design and install a radiative heat flux calibration facility*
Butler, Justin 5/01 to 8/01	Rochester Inst. of Technology Rochester, NY	Non-linearity determination of InGaAs detectors
Castelletto, Stefania 10/7 to 4/6/01	Istituto Electtrotecnico Turin, Italy	Development of a single photon source for quantum communications
Chen, Donghai *5/01 to 5/02*	*University of Florida* *Gainesville, FL*	*Rapid thermal processing (RTP) of materials*
Eckerle, Kenneth *1/00 to 6/01*	*Self*	*Develop spectrophotometric artifacts and standards*
Habauzit, Catharine 10/00 to 12/00	Universite Claude Bernary Cedex, France	Characterize the MOBY spectroradiometer and applied results taken in the filed.
Korter, Timothy 6/01 to 5/02	University of Pittsburgh Pittsburgh, PA	Provide research and development in spectroscopy
Molina-Vazque 8/01 to 9/01	Centro Nacional de Metrologia Queretaro , Mexico	Procedures to perform photometric and radiometric calibrations
Proctor, James *2/00 to 5/03*	*Jeptech, Inc* *Monrovia, MD*	*Planning a facility to measure spectral irradiance and radiance*
Saunders, Robert *5/01 to 12/01*	*Self*	*Collect and archive data from a UV monitoring station*
Stamilio, Rebecca *5/01 to 8/01*	*Appalachin State University* *Boone, NC*	*SURF*
Yokley, Charles *1/99 to 12/02*	*Self*	*Design and construct a PID system*

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OPTICAL TECHNOLOGY DIVISION (844) (Continued)

NAMES/DATES	SPONSORS	PROJECT
	Optical Properties and Infrared Technology Group	
Alicea, Emily 5/01 to 8/01	University of Puerto Rico Mayaguez, PR	Modeling SURF beam line
Carter, Adriaan 7/97 to 5/02	*Jung Research & Develop. Corp. Washington, DC*	*LBIR facility, ultra-high vacuum and cryogenic technology*
Colwell, Jack 2/01 to 1/02	Self	Proximity effect in low temperature superconductors
Gupta, Devinder 3/01 to 7/01	National Physical Laboratory India	Characterization of several materials selected for standard measurement
Jung, Timothy 10/95 to 5/02	*Self*	*Design and install experimental apparatus at the NIST LBIR Facility*
Lawler, Hadley 6/00 to 6/02	Univ. Maryland – College Park College Park, MD	Model far-infrared optical properties of material
Lorentz, Steven 3/01 to 3/02	*Self*	*Design and develop a 10 cm infrared collimator at LBIR*
Mekhontsev, Sergey 6/00 to 9/02	Vega International, Inc. New York, NY	Development of facilities for infrared-spectral-radiance/emittance characterization.
O'Connell, Joseph 11/00 to 5/04	*Jung Research & Dev. Center Washington, DC*	*Thermal infrared transfer radiometer*
Prokhorov, Alexandre 9/00 to 10/02	Vega International, Inc. New York, NY	Developing software tools for theoretical and ray trace studies of instrumentation
Raju, Sriramadas 9/01 to 8/02	Andhra University Andhra Pradesh, India	Characterizing the high accuracy prism-grating spectrophotometer
Sears, Dale 11/98 to 1/04	Jung Research & Dev. Corp. Washington, DC	Research assistance in the LBIR facility
Smith, Allan 7/00 to 5/04	Jung Research & Dev. Corp. Washington, DC	LBIR facility, ultra-high vacuum and cryogenic technologies
Soininen, Juha 1/00 to 9/02	Institut d' Optique Orsay, Cedex, France	Applications of correlated photon light sources
Soulen, Robert 9/00 to 12/02	Naval Research Laboratory Washington, DC	Proximity effect in low T_c superconductors
Tsolakidis, Argyrious 8/01 to 12/01	Univ. Illinois - Urban-Champaign Urbana, IL	Calculating optical spectra of solids

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NIST ASSOCIATES

OPTICAL TECHNOLOGY DIVISION (844) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Optical Properties and Infrared Technology Group (Continued)		
Woods, Gerald 9/01 to 8/03	Naval Research Laboratory Washington, DC	Spectral calibration of cryogenic black-bodies
Zhu, Changjiang 10/95 to 12/01	Jung Research & Dev. Corp. Washington, DC	Infrared spectrophotometric measurement instrumentation
Optical Sensors Group		
Galal, Susan 10/00 to 10/00	PTB Braunschweig, Germany	UV damage to photodetectors
Heimer, Todd *6/98 to 9/02*	*Self*	*Time-Resolved Laser Spectroscopy of Catalytic Polymerization Reactions*
Kranicz, Balacz 9/00 to 12/00	University of Veszprem Veszprem Hungary	Investigate the effects of various spectro-radiometer parameters
Manoocheri, Farshid 8/00 to 8/01	Helsinki U. Tech/Metl. Res. Inst. Hut, Finland	Investigate uncertainty of colorimetric measurements of visual displays
Santana, Carlos 5/01 to 8/01	University of Puerto Rico Mayaguez, PR	Tunable led-sphere source
Sauter, Georg 8/00 to 8/01	PTB Braunschweig, Germany	Photometry short course
Zhu, Qijun 6/98 to 4/01	Natl. Inst. Meas. Testing Tech. Changda, China	Design and development of point black-body
Zong, Yuqin 10/97 to 9/01	Shanghai Inst. Technical Physics People's Republic of China	Cryogenic radiometer
Laser Applications Group		
Bardo, Angela 8/01 to 8/03	University of Maryland College Park, MD	Optical studies of single molecule structure and dynamics
Branning, David 8/01 to 9/01	University of Illinois Urbana, IL	Inhibited emission from a parametric down converter
Campbell, Matthew 3/01 to 7/01	Sparta, Inc. Arlington, VA	Terahertz spectroscopy of biological spores and bacteria
Evans, Diane 12/99 to 12/02	University of Maryland College Park, MD	Characterization of thin films using near-field scanning optical microscopy

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OPTICAL TECHNOLOGY DIVISION (844) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Laser Applications Group (Continued)		
Hasselmann, George 9/00 to 3/02	John Hopkins University Baltimore, MD	Studies of the far-infrared spectroscopy of model DNA and protein systems
Heinz, William *1/00 to 10/02*	*John Hopkins University* *Baltimore, MD*	*Preparation and study of thin organic films and biological or biomimetic membranes*
Iwabuchi, Shinichiro 6/01 to 3/02	Japan Advance Inst. Sci. Tech. Ishikawa, Japan	Imaging animal cells and molecules using near-field scanning
Jacquier, Sandra 6/01 to 10/01	Universite Jean Monnet Saint-Etienne, France	Characterize the operational behavior of MHPOS1
Jolivet, Veronique 6/01 to 8/01	Institut d'Optique Cexde, France	Near-field optics
Kim, Junghyeun 5/00 to 5/02	University of Maryland College Park, MD	Measurement of light scatter
McWhorter, David *7/00 to 7/01*	*Self*	*Build, maintain and develop a transient far infrared (THz) laser spectrometer*
Navarro, Bertrand 4/00 to 10/00	Institut d'Optique Orsay, Cedex, France	Supervise the research on the application of near-field optics
Nguyen, Hoang-phi 6/01 to 8/01	Institut d'Optique Cedex, France	Researach on application of near-field optic
Sung, Lipiin 7/98 to 8/01	University of Maryland College Park, MD	Optical scattering metrology
Spectroscopic Applications Group		
Baranov, Yuri 10/01 to 8/02	Inst. Experimental Meterology Obninsk, Russia	Measuring thecontinuum absorption spectrum of water vapor
Bevan, John 9/00 to 9/01	Texas A&M University College Station, TX	Study weakly bound interactions using pulsed nozzle ft microwave spectroscopy.
Domenech, Jose 10/00 to 10/01	Con. Sup. Invest. Cientificas Madrid, Spain	Development of a terahertz spectrometer using dye lasers.
Flaud, Jean-Marie 7/00 to 8/00	Univ. Pierre et Marie Curie Osrsay Cedex, France	Analysis of the high resolution infrared spectrum of diborane.
Golubiantnikov, Guerman 2/00 to 1/01	Applied Physics Institute of RAS Nizhny Novgorod, Russia	Research in the area of terahertz spectros-copy.
Hougen, Jon **3/01 to 3/02**	**Self**	**Theoretical molecular spectroscopy**

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OPTICAL TECHNOLOGY DIVISION (844) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Spectroscopic Applications Group (Continued)		
Jacox, Marilyn 1/00 to 1/01	**Self**	**Spectroscopy of molecular ions**
Kawashima, Yoshiyuki 7/00 to 9/01	Kanagawa-Ken Inst. Tech. Kanagawa, Japan	Terahertz spectroscopy
Kleiner, Isabelle 6/99 to 8/00	University of Paris II Paris, France	Acetaldehyde spectra
Krohn, Burton 10/01 to 9/02	Self	Develop new theoretical methods in molecular spectroscopy
Lafferty, Walter 1/00 to 1/01	**Self**	**Spectroscopy of atmospherically important molecules**
Lavrich, Richard 7/00 to 7/01	Kent State University Kent, OH	Measuring the rotational spectra of isotopic molecules
Lee, Ronald 8/01 to 8/01	University of New Brunswick Fredericton, Canada	Research connected with DOE grant
Leonov, Igor 6/97 to 9/01	*Russian Academy of Science Nizhny Novgorod, Russia*	*FT microwave spectrometer*
Lin, Ping 9/00 to 9/00	Texas A & M University College Station, TX	Study weakly bound interactions using pulsed nozzle FT microwave spectroscopy
Lovas, Francis 3/00 to 3/01	Self	Submillimeter and THz spectroscopy studies
Ohashi, Nobukimi 8/00 to 8/00	Kanazawa Univ., Faculty of Sci. Kanazawa, Japan	Group-theoretical aspects of interpretation of the tunneling-rotation spectrum of DMMP
Romero, Danilo B. 8/96 to 8/01	University of Maryland College Park, MD	Infrared microscopy
Stevens, Walter 10/00 to 10/01	U.S. Department of Energy Germantown, MD	Terahertz spectroscopy of biomolecules
Suenram, Richard 4/00 to 3/02	*Self*	*FTMW spectra of chemical warfare agents and their by products*
Thompson, Warren 2/95 to 2/01	*Self*	*Matrix isolation spectroscopy*
Vigassine, Andrei 4/01 to 7/01	Obukhov Inst. Atmospheric Phys. Moscow, Russia	Study of bandshapes and dimer contributions to collision
Xu, Li-hong 8/01 to 8/01	University of New Brunswick New Brunswick, Canada	DOE contract to study vibrational quasi-continuum

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NIST ASSOCIATES

IONIZING RADIATION DIVISION (846)

NAMES/DATES	SPONSORS	PROJECT
Caswell, Randall 9/94 to 9/04	Self	Radiation transport calculations

Radiation Interactions and Dosimetry Group

NAMES/DATES	SPONSORS	PROJECT
Al-Sheikhly, Mohamad 8/01 to 8/04	University of Maryland College Park, MD	Radiation chemistry of basic mechanisms of ionizing radiation
Berger, Martin 5/00 to 4/02	Self	Interaction cross sections and transport algorithms
Darensbourg, Brandan 5/01 to 8/01	Southern Univ. & A&M College Baton Rouge, LA	Genetic programming & other techniques in Monte Carlo based photon teletherapy
Edwards, Emily 5/01 to 8/01	Appalachian State University Boone, NC	Characterization of radioactive seed sources for brachytherapy
Hubbell, John *8/01 to 6/02*	*Self*	*New and extended tabulation of critically evaluated photon mass attenuation*
Humphreys, Jimmy 3/96 to 12/01	Rayex Gaithersburg, MD	Irradiation of dosimeters and electron beams for accelerators
Kaur, Amapreet 6/01 to 8/01	Santa Monica College Santa Monica, CA	Simulate dosimetry calibration conditions and determine data correction procedures.
Loevinger, Robert 11/98 to 10/01	Self	Medical dosimetry, brachytherapy with radionuclides
McLaughlin, William **5/96 to 4/06**	**Self**	**Development of novel radiation sensors and analytical methods**
Motz, Joseph 8/88 to 12/02	Rayex Gaithersburg, MD	Development of power enhancement of x-ray tubes
Nad, Vitaly 10/98 to 9/02	Johns Hopkins University Baltimore, MD	Tooth enamel EPR method for retrospective dose assessment
Rao, Donepudi 9/99 to 3/01	Sir C.R.R. Antonomous Coll. Eluru, India	X-ray imaging techniques
Romanyukha, Alexander 12/98 to 2/02	Institute of Metal Physics Ekaterinburg, Russia	Electron paramagnetic resonance
Schauer, David 1/00 to 12/01	U.S. Navy, USUHS Bethesda, MD	Retrospective biodosimetry
Shiskina, Elena 8/01 to 10/01	U.S. Department of Energy Germantown, MD	Monte Carlo calculations
Sleptchonok, Olga 9/98 to 1/01	Johns Hopkins University Baltimore, MD	EPR tooth enamel method for retrospective dose assessment

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NIST ASSOCIATES

IONIZING RADIATION DIVISION (846) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Neutron Interactions and Dosimetry Group		
Allman, Brendan 3/01 to 3/01	University of Melbourne Victoria, Australia	Non-interferometric imaging
Alvine, Kyle J. 7/00 to 7/02	Harvard University Cambridge, MA	Ultracold neutron research
Anderman, Rachael 6/01 to 8/01	University of Missouri-Columbia Columbia, MO	Neutron polarization
Brome, Clinton 4/97 to 4/01	Harvard University Cambridge, MA	Neutron lifetime experiments
Carlson, Allan D. *6/01 to 9/01*	*Self*	*Improve evaluation of neutron cross section standards*
Doyle, John 4/97 to 4/02	Harvard University Cambridge, MA	Neutron lifetime experiments
Dzhosyuk, Segei N. 7/97 to 4/03	Harvard University Cambridge, MA	Neutron lifetime measurements
Eisenhauer, Charles *7/94 to 12/01*	*Self*	*Documentation of NIST computer codes for materials and personnel dosimetry*
Freedman, Stuart J. 8/92 to 12/00	University of California Berkeley, CA	Fundamental neutron physics/neutron interferometry
Fujikawa, Brian 6/96 to 12/00	Lawrence Berkeley Labs. Berkeley, CA	Fundamental neutron physics/neutron interferometry
Gabrielse, Joshua 7/00 to 7/02	Harvard University Cambridge, MA	Ultracold neutron research
Golub, Robert 6/98 to 6/02	Hahn-Meitner Institute Berlin, Germany	Ultra-cold neutron scattering
Greene, Geoffrey 6/96 to 6/01	Los Alamos National Lab. Los Alamos, NM	Fundamental neutron physics/neutron interferometry
Grundl, James A. 2/99 to 2/03	Self	Neutron fluence measurement
Haase, David G. 5/99 to 5/01	NC State University Raleigh, NC	Parity-violating rotation of neutrons
Hansen, Gregory L. 1/99 to 1/03	Indiana University Bloomington, IN	Neutron spin rotation experiment and neutron lifetime experiment
Hayward, Evans V. 1/98 to 9/02	Self	Interaction of neutrons and gamma rays with matter

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NIST ASSOCIATES

IONIZING RADIATION DIVISION (846) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Neutron Interactions and Dosimetry Group (Continued)		
Heckel, Blayne 11/96 to 9/01	University of Washington Seattle, WA	Fundamental neutron physics/neutron interferometry
Heyman, Daniel G. 5/01 to 8/01	Hamilton College Clinton, NY	Measuring the neutron lifetime by counting trapped protons
Jones, Gordon 2/98 to 2/02	Hamilton College Clinton, NY	^{3}He-based neutron spin filter
Korobkina, Ekaterina 4/01 to 4/01	Hahn Meitner Institute Berlin, Germany	Ultracold neutron experiments
Marella, Anthony *9/94 to 12/00*	*Self*	*Data acquisition equipment modifications*
Markoff, Diane 9/99 to 9/04	Triangle Univ. Nuclear Lab. Durham, NC	Parity non-conserving neutron rotation in liquid helium
Mattoni, Carlo 4/97 to 4/03	Harvard University Cambridge, MA	Measurements of the neutron lifetime
Maxwell, Stephen E. 7/01 to 7/03	Harvard University Cambridge, MA	Neutron lifetime experiment
McKinsey, Daniel 4/97 to 6/03	Harvard University Cambridge, MA	Measurements of the neutron lifetime
McMahon, Phillip 3/01 to 3/01	University of Melbourne Victoria, Australia	Non-interferometric imaging technique
Ratner, Daniel 6/99 to 6/01	Harvard University Cambridge, MA	Ultracold neutron trapping apparatus
Reinitz, Karl 2/98 to 2/02	General Activities, Inc. Arnold, MD	Solid-state neutron detectors
Schoen, Keary P. 5/00 to 5/02	U. of Missouri-Columbia Columbia, MO	Neutron interferometry
Schrack, Roald A. 5/94 to 7/02	Self	Neutron physics
Schwartz, Robert *3/96 to 9/01*	*Self*	*Investigate systematic effects in the calibration of neutron albedo dosimeters*
Smith, Todd 1/01 to 1/03	Indiana University Bloomington, IN	^{3}He-based neutron filters and fundamental physics with neutrons
Snow, William M. 4/93 to 12/02	Indiana University Bloomington, Indiana	Fundamental neutron physics/neutron interferometry

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NIST ASSOCIATES

IONIZING RADIATION DIVISION (846) (Continued)

Neutron Interactions and Dosimetry Group (Continued)

NAMES/DATES	SPONSORS	PROJECT
Wendell, Roger 5/01 to 8/01	Louisiana State U Baton Rouge, LA	Polarized 3He neutron spin filter development
Werner, Samuel *1/01 to 1/03*	*Self*	*Neutron interferometer and optics*
Wietfeldt, Fred 3/98 to 3/02	Harvard University Cambridge, MA	Fundamental physics experiments
Yang, Liang 11/00 to 9/02	Harvard University Cambridge, MA	Ultracold neutron research

Radioactivity Group

NAMES/DATES	SPONSORS	PROJECT
Bershell, Cari 5/01 to 8/01	Southern University Baton Rouge, LA	Standardization of ^{94m}Tc
Golas, Daniel 1/77 to 11/03	Nuclear Energy Institute Washington, DC	NEI-NIST measurement assurance programs
Hutchinson, J.M. Robin *1/98 to 8/01*	*Self*	*Development of new radionuclide detection techniques*
Hutchinson, J.M. Robin 8/01 to 8/03	Self	Development of new radionuclide detection techniques
Kaleas, Kimberly 6/01 to 8/01	Santa Monica College Santa Monica, CA	Mass spectrometric analysis of Pu isotopes (various sample loading methods)
McMahon, Ciara A. 8/99 to 6/02	University of Maryland College Park, MD	Produce reference materials
Nason, Lynne 2/98 to 12/02	Nuclear Energy Institute Washington, DC	NEI-NIST measurement assurance programs
Palabrica, Ofelia 11/92 to 11/01	Nuclear Energy Institute Washington, DC	NEI-NIST measurement assurance programs
Perez, Angelica 5/01 to 8/01	University of Puerto Rico San Juan, PR	Setup and test Ti:Sa laser for RIMS system
Pibida, Leticia *12/97 to 6/01*	*Self*	*Development of resonance ionization mass spectrometry*
Schima, Francis J. 1/00 to 1/02	Self	Radioactivity metrology by calorimetry
Wu, Zhongyu 5/98 to 11/01	University of Maryland College Park, MD	Measurement of low-level radionuclides

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NIST ASSOCIATES

TIME AND FREQUENCY DIVISION (847)

NAME/DATES	SPONSORS	PROJECT
	Ion Storage	
Ben-Kish, Amit 9/00 to 12/01	Rafael Laboratory Technion City, Haifa, Israel	Quantum-state engineering using Be^{+} ions
Britton, Joe 8/00 to 8/02	University of Colorado Boulder, CO	Perform and assist with ion storage experiments
Cruz, Flavio 7/01 to 7/01	UNICAMP Campinas, Brazil	Optical frequency synthesis with pulsed TI: sapphire laser
Hughes, Kenneth *2/15 to 8/01*	*University of Colorado* *Boulder, CO*	*Ion storage experiments*
Jelenkovic, Branislav *11/99 to 11/02*	*Self*	*Penning Trap experiments*
Jensen, Marie 9/01 to 9/03	University of Colorado Boulder, CO	Ion storage experiments
Kielpinski, David 6/99 to 8/01	University of Colorado Boulder, CO	Ion storage experiments
Kurosu, Takayuki 7/01 to 8/01	National Inst. Adv. Industrial Sci. Tech.: Kobe, Japan	To investigate simpler, smaller and better isolation platforms
Langer, Christopher 8/01 to 8/03	University of Colorado Boulder, CO	Ion storage experiments
Leibfried, Dietrich 3/01 to 3/03	University of Colorado Boulder, CO	Quantum logic devices
Meyer, Volker 10/99 to 9/02	University of Heidelberg Ibaraki, Germany	Ion storage experiments
Quraishi, Qudsia 5/01 to 7/01	University of Colorado Boulder, CO	Beryllium ions stored in a Penning Trap
Rowe, Mary 8/01 to 8/03	University of Colorado Boulder, CO	Ion storage experiments
Rosenband, Till *6/01 to 5/02*	*Self*	*Ion storage experiments*
Tanaka, Utako 10/00 to 9/01	Kansai Adv, Res. Center/Com. Research Lab.: Kobe, Japan	Support of single-mercury ion optical frequency standard
Tanner, Carol *9/01 to 8/02*	*Notre Dame* *Manchester, NH*	*Development of a clock that oscillates at an optical frequency*

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NIST ASSOCIATES

TIME AND FREQUENCY DIVISION (847) (Continued)

NAMES/DATES	SPONSORS	PROJECT
	Phase Noise Measurements	
Garcia-Nava, Francisco 3/00 to 7/02	*Self*	*Phase noise measurements*
Hati, Archita 4/01 to 3/02	Burdwan University Burdwan, India	Ultra low noise characteristics of synthesizers
Lujan, GianCarlo 8/00 to 8/01	University of Colorado Boulder, CO	Phase noise measurements
Martinek, Brianne 5/00 to 5/01	University of Colorado Boulder, CO	Provide computer and engineering support to Division 847 staff
Pond, Paul 10/00 to 10/02	*Self*	*Repair and modify critical hardware for phase noise measurements*
Smilkstein, Jarod 1/01 to 6/02	University of Colorado Boulder, CO	Phase noise measurements
Walls, Fred 11/00 to 11/02	Self	Phase noise measurements
	Time and Frequency Services	
Hanson, Donald Wayne 2/01 to 2/03	Self	Replace antennas at WWVH, vice Chairman of ITU-R, SSG-7
Heidecker, Jason 3/99 to 3/03	*Self*	*Engineering support in equipment test and assembly*
Le, Kha 1/01 to 1/03	University of Colorado Boulder, CO	Assembly, modification, repair to electrical/technical equipment
Webster, Ken 1/00 to 12/01	*University of Colorado Boulder, CO*	*Provide engineering support to radio stations and Division 847*

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NIST ASSOCIATES

TIME AND FREQUENCY DIVISION (847) (Continued)

NAMES/DATES	SPONSORS	PROJECT
	Atomic Standards	
Calosso, Claudio 6/01 to 8/01	Politecnico Di Torino Torino, Italy	To assist in investigation of 2nd generation fountain clocks
Kujundzic, Damir 3/00 to 5/02	University of Belgrade Zeoman, Beograd, Yugoslavia	Construction and testing of a new laser cooled cesium clock
Levi, Filippo 7/01 to 8/01	Inst. Elettrotecnico Nazionale Torino, Italy	Assist in the investigation of 2nd generation fountain clock
Shirley, Jon *10/87 to 3/02*	*Self*	*Develop theoretic models for the expected systematic errors.*
Stepanovic, Momir 10/99 to 9/02	University of Colorado Boulder, CO	Cesium fountain primary frequency standard
	Optical Frequency Measurements	
Brown, John 3/01 to 3/01	Oxford University London, UK	Tunable far infrared laser spectroscopy experiments
Curtis, Elizabeth Anne 6/99 to 6/02	University of Colorado Boulder, CO	Optical frequency measurements
Evenson, Kenneth 3/00 to 2/01	SELF Boulder, CO	Laser spectroscopy experiments
Holman, Kevin *1/01 to 5/01*	*University of Colorado* *Boulder, CO*	*Provide assistance to Optical Frequency Measurements Group*
Ivanov, Eugene 6/01 to 6/01	University of Western Australia Nedland, Australia	Low noise amplifiers, oscillators & measurement systems
Jackson, Michael 6/01 to 6/01	University of Wisconsin La Crosse, WI	To assist in cleaning up the laser spectroscopy lab
Jennings, Donald *12/99 to 12/02*	*Self*	*Optical frequency measurements*
Kitching, John 9/99 to 9/02	University of Colorado Boulder, CO	Semiconductor diode lasers
Mackie, Neil *6/99 to 6/02*	*Self*	*Laser research and vacuum system development*
Magyar, John *5/00 to 5/02*	*Self*	*Optical frequency measurements*

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NIST ASSOCIATES

TIME AND FREQUENCY DIVISION (847) (Continued)

NAMES/DATES	SPONSORS	PROJECT
Optical Frequency Measurements (Continued)		
Mizushima, Masataka 2/00 to 2/02	University of Colorado Boulder, CO	Detection of gravitational waves
Mullen, Lewis *3/99 to 3/02*	*Self*	*Repair and modification of vacuum parts, clean up and organize laser laboratory*
Penella, Colleen *10/00 to 5/01*	*Self*	*Paperwork and clerical duties*
Sanford, Quinn 6/01 to 6/01	University of Wisconsin La Crosse, WI	Cleanup of laser spectroscopy laboratory
Simmons, Sandra *6/01 to 8/01*	*Self*	Cleanup of laser spectroscopy laboratory
Stahler, Markus 6/01 to 11/01	Institute for Applied Physics Bonn, Germany	Diode laser pumped Rb & Cs atomic clocks
Sullivan, John 6/01 to 6/01	University of Wisconsin La Crosse, WI	Cleanup of laser spectroscopy laboratory
Taichenachev, Aleksei 7/01 to 12/01	Novosibirsk State University Novosibirsk, Russia	Design advance schemes for laser cooling neutral atoms
Udem, Thomas 1/01 to 2/01	Max-Planck Inst. f. Quantenoptik Graching, Germany	Discuss collaborative research experiments
Vershure, Eric 6/01 to 6/01	University of Wisconsin La Crosse, WI	Cleanup of laser spectroscopy laboratory
Wells, Joseph *6/99 to 6/02*	*Self*	*Heterodyne frequency measurements on gases*
Wynands, Robert 7/01 to 7/01	Bonn University Germany	Diode laser pumped Rb & Cs atomic clocks
Yudin, Valerii 7/01 to 12/01	Novosibirsk State University Novosibirsk, Russia	Design advance schemes for laser cooling of neutral atoms

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NIST ASSOCIATES

Quantum Physics Division (848)

NAMES/DATES	SPONSORS	PROJECT
Bililign, Solomon 1/01 to 6/01	North Carolina A&T State Univ. Greensboro, NC	Experimental and theoretical Atomic, Molecular, and/or Chemical Physics.
Child, Mark 11/01 to 4/02	Physics & Theoretical Chemistry Lab Oxford, U.K.	Molecular Collision Theory
Christov, Ivan 7/01 to 10/01	Sofia Univeristy Sofia, Bulgaria	Ultrafast phenomena, modeling, etc.
Cordes, James 9/01 to 2/02	Cornell University Ithaca, NY	Interstellar Turbulence
DePaola, Brett 8/01 to 5/02	Kansas State University Manhattan, KS	Ion-atom Collisions
Hänsch, T. W 2/01 to 2/01	MPI f Quantenoptik Garching, Germany	Frequency combs and absolute frequency metrology, BEC and Guiding Atoms
Herman, Zdenek 1/01 to 7/01	Academy of Sci. Czech Republic Prague, Czech Republic	Ion-molecule Reaction Dynamics
Hutson, Jeremy 7/01 to 7/02	University of Durham Durham, UK	Van der Waals complexes
Jhe, Wonho 9/01 to 9/02	Seoul National University Seoul, Korea	Bose-Einstein Condensation
Knight, Alan 10/00 to 2/01	Griffith University Brisbane, Australia	Combination of the discharge slit jet
Meijer, Gerad 5/01 to 6/01	FOM-Institute for Plasma Physics Nieuwegein, Netherlands	Sensitive detections, flame dynamics, and cold molecules.
Pitaevskii, Lev 8/01 to 2/02	University of Trento Trento, Italy	Bose-Einstein Condensates
Shlosman, Isaac 7/01 to 7/02	University of Kentucky Lexington, KY	Star formation
Van Leeuwen, K.A.H 6/01 to 10/01	Eindhoven University of Technology Eindhoven, Netherlands	Quantum optics and atom wave optics

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SUMMARY OF STAFF ON BOARD AS OF 9/30/2001

	Division	No. of FTP	% of FTP	Other than FTP	% of Other
Scientific and Engineering staff including Postdocs	840	6	3.0%	2	3.9%
	841	18	9.1%	8	15.7%
	842	24	12.1%	12	23.5%
	844	35	17.6%	9	17.6%
	846	29	14.6%	3	5.9%
	847	28	14.1%	3	5.9%
	848	9	4.5%	4	7.8%
Technicians and Lab Assistants	840	0	0.0%	1	2.0%
	841	4	2.0%	0	0.0%
	842	2	1.0%	0	0.0%
	844	1	0.5%	6	11.8%
	846	5	2.5%	0	0.0%
	847	3	1.5%	0	0.0%
	848	0	0.0%	0	0.0%
Clerical and Administrative	840	7	3.5%	1	2.0%
	841	3	1.5%	1	2.0%
	842	8	4.0%	0	0.0%
	844	5	2.5%	0	0.0%
	846	4	2.0%	0	0.0%
	847	6	3.0%	1	2.0%
	848	2	1.0%	0	0.0%
		199+	100%	51+	100%

SUMMARY OF STAFF BY TYPE OF APPOINTMENT AS OF 9/30/2001

Type of Appointment	840	841	842	844	846	847	848	Total
FTP	13	25	34	41	38	37	11	199
Part-Time	0	0	0	0	1	2	0	3
Postdoctorals	0	4	6	5	1	2	4	22
Non Employees*	5	35	73	78	66	55	0	312
Intermittent-WAE's	4	4	2	10	1	0	0	21
Term Appointments	0	0	4	0	0	0	0	5
	22	69	119	134	107	96	15	562

+Of the 250 total staff, 190 are scientific and engineering staff, 146 or 77% of whom have a Ph.D.

*Includes all non-employees, including 3 in Division 846 with user agreements at the NIST Reactor.

PROGRAM PLANNING

Background. The Physics Laboratory directs its programs towards the needs of industry and the technical community. We apply fundamental concepts in atomic, molecular, optical, surface, solid state, and radiation physics to the development of innovative measurement techniques needed for industrially and technologically important processes and standards. The two common themes that dominate our plans and proposals are: (1) physics applied to support emerging technologies; and (2) physics applied to developing advanced measurement standards. Quality and innovation are the two most important elements that we look for in all of our programs. If there is a proposal that is revolutionary in concept or has the potential of advancing the state-of-the-art in a major way, we will include it in our planning and fund it to the extent possible.

Evaluating Technical Merit and Appropriateness of Work. The Measurements and Standards Laboratories at NIST are mission oriented, with each laboratory serving specific industry and technology sectors identified by Institute management. The Physics Laboratory serves the national interest by providing measurement services and directed research in the physical sciences to support optical, electronic, and radiation technologies. Through the Laboratory's strategic planning process, Laboratory management identifies research and measurement services that should be supported to best fulfill our mission.

We evaluate the quality and impact of our work by maintaining a close working relationship with our customers. For example, the Physics Laboratory has worked with its customers to establish the Council for Optical Radiation Measurements (CORM) and the Council for Ionizing Radiation Measurements and Standards (CIRMS) as a means for Physics Laboratory staff to regularly meet with key representatives in the optics and ionizing radiation industries. These interactions help ensure that the technical staff and line management are kept apprised of current industry trends, and they provide a means by which Physics Laboratory management can evaluate how well our current programs are meeting their defined goals. Moreover, this same process is used to determine when our efforts in any particular area are no longer the most effective utilization of our operating resources.

This process has had a tremendous impact on our scientific and technical performance. In responding to the needs of our industrial customers and the feedback we receive from them, we have continuously improved the capability of our laboratories so that they remain at, or among, the world's leading facilities. These interactions also enable staff and management to identify emerging national needs in the fields and, thereby, to contribute to our strategic plan.

When a new area is identified and a favorable decision to enter that area is made, the performance objectives and the criteria to be used for determining success are defined at project inception. In this manner, the quality and impact of the work conducted by each project within the Physics Laboratory are critically evaluated with respect to the goals defined in the Laboratory's strategic plan. This is typically done by a consensus of the Laboratory Director's office, the Division Chiefs, and the Group Leaders. Individual performance plans of the scientists and managers contain dated milestones that are used to assess the ongoing success of projects. As such, the performance plans reflect the Laboratory's strategic plan.

One of the most important strategic elements of NIST's mission is to maintain primary responsibility for many of the national and international standards that govern the conduct of our Nation's commerce. NIST scientists and engineers engaged in standards activities participate on pertinent national and international standards committees. NIST as a whole, and the Physics Laboratory in particular, exercises a strategic approach regarding the participation of its staff members on standards committees. The strategy seeks to maximize the impact of relevant NIST programs by linking individual standards activities to organizational units and their missions. In doing so, once the pertinent committee activities have been identified, appropriate resources are committed to support the activity.

The priorities and responsibilities of individual staff members tasked with standards activities are coordinated with their other duties. Their standards-related activities are tracked as part of the overall performance management program. NIST further supports standards committee activity through the Office of Standards Services, a component of Technology Services, one of the 12 main organizational units at NIST.

■ **Assessing Impact of Programs.** In planning its programs, the Physics Laboratory tries to identify, whenever possible, generic industrial issues and needs so as to achieve the broadest possible impact. Physics Laboratory staff respond to the needs of the various U.S. industrial sectors they serve, not only by responding to direct requests for new or improved products and services, but also by discerning and anticipating future needs. Often the requisite insight into potential future needs of industry is obtained through active participation in the vast array of standards-writing bodies (most notably the American Society for Testing and Materials) and professional societies to which Physics Laboratory staff members belong.

Equally important are the outreach efforts whose purpose is to identify and forecast customer measurement needs; e.g., our cooperation with CORM and CIRMS. Another useful method is through formal surveys; e.g., the Time and Frequency Users Survey. Moreover, the Physics Laboratory has provided critical leadership to several studies that forecast national needs in various technology sectors. This includes the NAS/NRC reports:

- Atomic, Molecular and Optical Science, an Investment in the Future;
- Plasma Science, From Fundamental Research to Technological Applications;
- Harnessing Light, Optical Science and Engineering for the 21st Century; and
- National Needs in Ionizing Radiation Measurements and Standards.

Last year Physics Laboratory and other NIST staff participated in a national workshop on *Nanotechnology Research Directions*. This formed the basis of the President's decision to launch a national initiative in this area in FY 2001.

A new calibration program serving the nuclear medicine industry exemplifies the success of these efforts. As a direct consequence of the interaction between Physics Laboratory scientists and health care professionals working in the field of nuclear medicine that was fostered by CIRMS, the Ionizing Radiation Division inaugurated a new calibration service for radioactive seeds used in cancer brachytherapy treatments. This service is presently one of NIST's highest-volume calibration services and its most rapidly expanding service. Another example is the development of a colorimetry measurement program for light emitting diodes (LEDs). Because these sources of visible radiation are seen as an important, low power illumination resource for the future, Physics Laboratory scientists in the Optical Technology Division are actively developing a measurement and calibration program to address the anticipated needs of the lighting industry relative to the use of LEDs for large-scale commercial applications.

Physics Laboratory scientists also actively participate in the development of technology roadmaps. These are very important in helping NIST determine future national measurement needs. Some examples include roadmaps developed for the Semiconductor Industry Association, the Optoelectronics Industry Development Association, and the National Storage Industry Consortium.

The aforementioned tools (the councils, needs-reports, roadmaps, etc.) provide a scale by which the Physics Laboratory can assess the responsiveness of its measurement programs towards addressing the needs of relevant U.S. industries and the relative impact our services have on them. NIST seeks to ensure that its measurements programs are state-of-the-art and best in the world.

■ **Managing Resources: Inter-Laboratory Activities, Equipment, and Facilities.** Within NIST, interdisciplinary research conducted across organizational lines is strongly encouraged. There are no barriers to discourage research endeavors of this type. Collaborations may develop either directly and strategically in response to national needs in a particular field of science or technology, or they may be based upon the specific needs of individual researchers. For example, in the Optical Technology Division, research is being conducted on *Sum Frequency Generation Studies of Thin Organic Films: Biomimetic Membranes and Polymer Interfaces*. This project involves an extensive collaboration of scientists from the Physics Laboratory, the Biotechnology Division and the Surface and Microanalysis Science Division of the Chemical Science and Technology Laboratory, and the Polymers Division of the Materials Sciences and Engineering Laboratory. Another collaboration between the Physics Laboratory's Electron and Optical Physics Division, the Mathematical and Computing Sciences Division of the Information Technology

Laboratory, and the Intelligent Systems Division of the Manufacturing Engineering Division, is developing a nano- robotic system for autonomous control of a cryogenic STM system designed to manipulate individual atoms and fabricate custom-made nano-structures. This system will be the only one of its kind in the world.

Necessary funds for capital equipment purchases for each of the Physics Laboratory's six divisions and two programs are carefully evaluated relative to the Laboratory's overall strategic plan and integrated into each Division's annual operating budget. Additional money at the Laboratory level is made available each year for the purchase of additional capital equipment. Moreover, the acquisition of capital equipment is considered within the framework of research funded in part by other agencies, and research and development work performed in collaboration with industry.

A new, advanced measurement laboratory (AML) is being constructed in Gaithersburg for experiments requiring the best of conditions. Several Physics Laboratory projects will occupy this space, starting in FY03. As the construction project progresses, NIST staff continually evaluate the AML design to ensure that it will meet the changing requirements of the projects. Teams not only evaluate conventional aspects such as the facility's mechanical and electrical capabilities, but also its specialized features such at the requirements of temperature control and vibration isolation systems.

■ **Congressional Budget Initiatives**. In the following pages we provide short descriptions of NIST budget initiatives submitted to Congress through the Department of Commerce and the Office of Management and Budget that are relevant to the funding of high priority programs in the Physics Laboratory.

Two initiatives potentially affecting the Physics Laboratory were submitted for consideration for FY01 funding (October 1, 2000 to September 30, 2001). These were:

- *Nanotechnology*
- *Optical Technology*

The nanotechnology initiative was part of President Clinton's National Nanotechnology Initiative. Announced on January 21, 2000, with considerable national press coverage, including prime-time, live, media interviews with the President's Science Advisor and the Director of the National Science Foundation on Air Force 1, the national initiative was to include 6 agencies and almost a quarter billion dollars of new research funding. A copy of the White House press release is included in this section. The Congressionally approved $2M budget increase for NIST was used to expand existing nanotechnology projects at NIST that had been initiated with Director's reserve or competence funding and to fund collaborations with groups outside NIST that represent strategic partnerships and are synergistic with NIST goals.

One of our staff played a significant role in the development of the national nanotechnology initiative. R. Celotta, a NIST Fellow and Leader of the Electron Physics Group in the Electron and Optical Physics Division, was a workshop participant and author of part of the report issued by the Interagency Working Group on Nanoscience, Engineering, and Technology, contributing to sections on *Fundamental Scientific Issues*, *Nanodevices*, *Nanoelectronics and Nanosensors*, and *Experimental Methods and Probes*. This is only the most recent contribution by the Physics Laboratory which has been among the pioneers in nanotechnology for the last 15 years.

NIST was not as successful with the FY01 optical technology initiative. It was recommended to OMB by the Department of Commerce, but was not adopted as part of the President's budget request to Congress. Because of its continued importance in our planning process, a copy of the proposal is included in this section.

To support the development of an optical technology initiative, PL organized staff visits to industrial laboratories. We met with company presidents, senior executives, and technical representatives of 24 organizations in Connecticut, Florida, New York, Arizona, New Mexico and Maine to get a first-hand perspective on the needs of the U.S. optics industry for measurement methods, standards, reference data, and research on new technologies. At the same time we described the capabilities of NIST in optical technology, opportunities for future cooperation, and our plans for expanding R&D and services in support of the optical industry. This was done in cooperation with representatives from the NIST Manufacturing Engineering Partnership Program and Technology Services and in response to some of the recommendations from the 1998 NRC Report, *Harnessing Light: Optical Science and Engineering for the 21st Century*.

■ **Competence Proposals**. The thrust of competence building proposals is high-risk research to provide new, basic measurement techniques and fundamental data. Successful projects are expected to continue and perhaps expand after competence funding ends. As a result, competence proposals reflect an area of strategic importance to a Laboratory's core research program.

There were some major changes in this year's process for selecting FY01 competence projects. The NIST Director decided that fewer, but larger, awards would be made for proposals that were ambitious, collaborative in nature, and potentially most far-reaching in their impact. It was also decided that the Directors of all the NIST organizational units would participate in the final selection process.

In this process, 7 proposals from the Physics Laboratory were submitted for consideration. One of them was selected for funding, *Quantum Information*, a major collaboration between experimentalists and theoreticians in the Physics Laboratory's Time and Frequency Division, Atomic Physics Division, and Electron and Optical Physics Division. The project envisions active collaborations with the Mathematical and Computational Sciences Division of the Information Technology Laboratory, scientists outside NIST, and other government agencies, e.g., the National Security Agency and DARPA.

CONGRESSIONAL BUDGET INITIATIVES

FY 2001

NIST Nanotechnology Initiative (Partially Funded)

All Physics Laboratory Divisions, with Divisions of the Electronics, Chemical, Materials, and Manufacturing Research Laboratories.

Optical Technology Initiative (Unfunded)

All Physics Laboratory Divisions, with the Optoelectronics Division of the Electronics and Electrical Engineering Laboratory

CONGRESSIONAL BUDGET INITIATIVE PROPOSAL FY 2001 – PARTIALLY FUNDED

TITLE: Nanotechnology

DIVISIONS: All Physics Laboratory Divisions, with the Electronics, Chemical, Materials, and Manufacturing Research Laboratories

OBJECTIVE

To provide measurements, standards, and test methods for private sector development of advanced nanotechnologies, including applications in most major industrial sectors such as health care, semiconductors, communications, defense, biotechnology, and magnetic data storage. These measurements and standards are needed to ensure U.S. economic and technical leadership in these key fields which will be increasingly driven by advances in nanotechnology. NIST will develop the critical enabling infrastructural measurement and standards in the areas of nanodevices, nanomagnetics, nanomanipulation, and nanocharacterization. These efforts support the White House nanotechnology priority and the recommendations of the President's Committee of Advisors on Science and Technology.

PROBLEM MAGNITUDE AND NIST ROLE

Nanotechnology will be a dominant technology in the next century. Only recently possible, nanotechnology represents the ultimate in manufacturing through the knowledgeable use of the building blocks of all matter – atoms and molecules. This new capability has the potential to fundamentally change our everyday lives. U.S. industry, including manufacturing, materials, health care and electronics, will use nanotechnology in the future or find that they cannot effectively compete in global markets. This field offers tremendous opportunities for economic growth and improvement in U.S. competitiveness. The small size and low expense of nanodevices will expand the reach of technology to all areas of the U.S. For example, nanotechnology solutions to health care diagnosis systems – the "lab-on-a-chip" – will allow the most remote areas of the U.S. to have the most advanced health care technologies. Supporting industrial nanotechnology applications requires NIST to develop a new genre of standard materials, data, and measurement systems specifically designed for the nanoworld. The technical risks in this world are very high as an individual molecule that is "out-of-place" may cause a device to fail. But the new discoveries and materials being generated in nanotechnology offer countless opportunities for commercial innovation, from bio-implants that automatically regulate pharmaceutical dosage to atomic manipulation in a manufacturing plant that creates new ultrahigh density data storage media. All these new technologies require atomically accurate measurement capabilities, standard materials and data to allow industry to design, manufacture, and assure the quality of their products.

European and Japanese governments are investing heavily in nanotechnology research. NIST must significantly increase its work with U.S. industry to develop the measurement and standards infrastructure that is crucial for this innovation and to ensure that technical requirements of international standards do not put U.S. manufacturers at a disadvantage.

NIST's fundamental mission is to support U.S. industry with the measurements, standard materials and data needed for global competitiveness and to ensure continued economic growth. NIST is the only organization that has the mission and the necessary combination of staff expertise, experience, industry contacts, industry respect, and worldwide recognition as the leading measurement and standards institution. NIST has unique experience in working with the breadth of industries impacted by nanotechnology, from electronics to biotechnology. Research into such measurement areas as quantum electron counters for high accuracy electrical calibrations, giant magnetoresistance for magnetic data recording, DNA diagnostics for health care, and atomic scale imaging and spectroscopies for semiconductor technology has made NIST a world leader in nanotechnology. NIST staff expertise in materials, electronics, physics, chemistry, and manufacturing technology makes NIST uniquely qualified to address the high risk scientific and technological challenges associated with developing the measurement techniques and technical standards needed in this new field.

NIST is a member of the NSTC Interagency Working Group on Nanotechnology and is coordinating our efforts with other Federal scientific agencies to ensure their programs will have the enabling measurements and standards necessary for success.

PROPOSED NIST TECHNICAL PROGRAM

At the proposed funding level, NIST will develop the critical enabling infrastructural measurement and standards in the areas of nanodevices, nanomagnetics, nanomanipulation, and nanocharacterization.

Nanotechnology depends on the manipulation of quantities of matter on the order of single atoms and molecules. This manipulation can be approached from two directions, commonly referred to as the "top-down approach" and "bottom-up approach" to manufacturing things with nanodimensions. Top-down technologies, such as semiconductors and magnetic data storage, have evolved over the years from large centimeter scales down to smaller and smaller dimensions, until they will soon approach atomic or nanoscale dimensions. Top-down manufacturing is the source of most existing and near-future industrial applications of nanotechnology. Semiconductor manufacturing tools such as lithography permit structures to be mass manufactured with critical dimensions at the 200 nm (nanometer) level, with finer structures at the 70 nm level and below proposed by the year 2008. The same technology used to create computer chips can be applied and modified to develop a wide array of new nanotechnologies, including bioelectronic devices for health care and new measurement systems for absolute calibration. The nanodevices and nanomagnetics portions of this initiative will provide industry's measurement and standards needs for current and near term applications of nanotechnology. In the nanodevice portion, NIST applies these top-down approaches to the development of new measurement and calibration methods and standards.

Bottom-up manufacturing – building useful objects from single atom or molecular building blocks – is based on nanomanipulation and is the source of new nanomaterials such as fullerenes, carbon nanotubes, and novel demonstrations such as recording information by selective placement of single atoms. Such work is the likely basis of scientific advances that will lead to future commercial applications. The instrumentation to accomplish such manipulations of matter, to characterize the results, and to interact with the products is the critical core of nanotechnology. The nanocharacterization focus of the initiative is for the development of measurements and standards that are necessary for all approaches to nanotechnology and are in high demand by a broad base of U.S. industries.

Nanotechnology is a broad field with diverse industry needs. In order to leverage our efforts and efficiently and effectively meet the measurement and standards needs of U.S. industry while maintaining our institutional flexibility and responsiveness to rapidly changing customer needs, NIST will develop stronger strategic alliances/collaborations with universities, businesses and other government agencies that possess leading expertise in nanotechnology to conduct much of the specific work required to meet the goals of this initiative and avoid developing costly, complex in-house capabilities that will be used only once. The university alliances will also help educate the U.S. workforce in nanotechnology related problems, and permit NIST scientists and engineers to concentrate on the critically needed metrology and research, while contracting out development of specific equipment and techniques. Building these partnerships will return greater value to the taxpayers for their investment in nanotechnology.

Nanodevces: NIST will develop measurements and standards for the nanotechnology industry using the evolving top down approach, including the semiconductor, communications, and health care industries. NIST will also use the top-down approach to develop new measurement techniques and standards. This focus will allow NIST to meet the short- to medium-term needs of U.S. industry. NIST proposes the following areas of nanodevice research:

- NIST will develop a suite of quantum standards that attain near absolute accuracy for exact calibration of physical parameters (e.g., electrical, mass, force, and chemical analysis.)
- NIST will develop measurements and standards that support the use of new semiconductor processing and manufacturing approaches, including: standard data to support deep UV and x-ray lithographic methods; measurement techniques to

determine the effectiveness of plasma processing and rapid thermal processing; X-ray optics and single-ion etching/lithography; and a variety of dimensional, electrical, chemical, nanoparticle contamination, and other standard materials that will be made to meet the rising demand from the semiconductor manufacturing industry.

- Nanoscale versions of table-top analysis instruments, frequently referred to as "lab-on-a-chip" technology, promise to revolutionize many chemical and physical measurements with wide ranging applications in health care, environmental, and industrial process monitoring. These devices will move many laboratory measurements into the field, e.g., to the doctor's office or the plant floor. NIST will develop measurements and standards supporting this growing technology area, including dimensional, chemical, and electrical standards that are needed to assure the quality of results from these devices. The masses and volumes measured by these devices are much smaller than previously attained and NIST will need to develop methods to make standards that are homogeneous at the nanoscale level, a new requirement for many of our standard materials.

Nanomanipulation: The bottom-up synthesis approach uses nanomanipulation to develop nanomaterials and devices, such as self-assembled monolayers and multilayers and scanning probe manipulators, from atomic and molecular scale manipulation. This initiative in nanomanipulation will include the following areas:

- To achieve high volume production in nanoscale manufacturing, it will be necessary to mimic nature's strategy of self-assembly and self-replication. Progress in the area of self-assembly of thin films is being made; however, better measurements of the forces governing self-assembly are needed to enable assembly of the complex structures desired for catalysis, sensing, molecular separations, biomaterials, and molecular electronic devices. NIST will develop standards for autonomous atom assembly to permit detailed measurement of their physical, electronic and magnetic properties.
- Many manufacturing processes can be controlled and manipulated in more accurate and novel ways if we understand the mechanics of nanoscale systems, including nanofluidics and nanoparticulates. NIST will develop single particle tracking, manipulation, and measurement methods for investigation of molecular transport in biological, biomimetic, and bioengineered metallic oxide films and membranes and other manufacturing processes.
- A great challenge for computational research is the accurate and reliable estimation of the properties, reactivity, and bulk behavior of molecules in the condensed phase, including solutions, surfaces, solids, and interfaces. NIST will integrate first-principles, predictive quantum methods with atomistic statistical methods for sampling configurations and properties at finite temperature and pressure. To date, this has been accomplished for only the simplest systems. This capability will supercede current empirical methods and simplistic models. Many roadmaps and workshops have highlighted the need for work in this important area from the point of view of process and product design in the 21st century.

Nanocharacterization: Tools for visualization and characterization are vital to understanding nanotechnology. Measurement and characterization at the nanoscale are necessary to understand the nature of nanomanufacturing processes, to assess the purity of nanoscale products and components, and to understand mechanisms of interaction of the product with its environment, including failure during operation. Industry requires a new set of characterization tools and standards since existing characterization approaches and standards are insufficient, lacking the necessary spatial resolution or specificity needed for nanotechnology. Industry cannot successfully make nanodevices or components until they can be accurately measured and characterized. NIST will develop measurement methods and standards that allow atomic scale resolution in three dimensions with accurate physical and chemical functional specificity. NIST proposes:

- To develop smart measurement probes sensitive to electronic, magnetic, chemical or biological properties, e.g., a nano-tip including a single electron transistor for ultrasensitive charge measurements, a superconductor tip for electron spin detection, or chemically/biologically functionalized tips for nanoscale analysis to support semiconductor, chemical and materials processing, pollution monitoring, medical diagnosis, and food quality control. The weak link in such measurements has always been the specificity of the detection material. The recent development of molecularly-tailored nanostructures composed of metals, semiconductors, polymers, or DNA opens exciting new opportunities for sensing. NIST will develop both new sensors and the electrical and optical measurement methods to enable the use of these chemically and physically selective nanomaterials in measurement devices. These new probes will allow NIST to support the increasing use by industry of combinatorial approaches to materials characterization and synthesis.

• To develop measurement instrumentation and the theoretical basis for interpreting images and analyses including the quantitative 3-D measurement methods to allow accurate interpretation of chemical, physical, and dimensional data from these new technologies, neutron and x-ray reflectometry, small angle scattering, and spectroscopic analysis, and standard materials and data. The techniques of microscopy and nanoanalysis based upon beams of electrons, ions, photons, neutrons and scanned probes are key assets in the nanotechnology fields.

Nanomagnetics: The magnetic data storage industry is an example of the widespread commercialization of nanotechnology. Magnetic storage bits on new computer hard disks currently measure 80 nm by 500 nm, and read/write head flying distances are only 20 nm. The trend in information storage continues toward higher information density and higher access speed, both of which double every two to three years. Many problems and challenges face the magnetic information storage industry at this especially critical time. NIST proposes to work in the following areas:

• Magnetic Bit Stability and Kinetics in Thin Films. NIST will develop ultra-high-speed measurements of magnetization dynamics for characterization of speed capabilities of thin film materials to support gigabyte storage. At the other extreme is the need for multi-year stability of a bit once it is written, despite thermal fluctuations, which can degrade very small-area bits. Measurements and models will be developed to meet these industrial needs.

• Imaging Methods for Nanomagnetics. With recording bits having sizes as small as 250 nm by 25 nm, being able to image possibly misaligned magnetic structures as they are recorded is a critical capability for design engineers. NIST will realize this measurement capability with the development and application of a microscope which uses electron spin and other methods to image magnetic domains.

• Physical Standards for Magnetic Measurements. New standards are needed by industry for measurements on read/write heads and magnetic disks. This project will produce standards for films having a magnetic moment 100,000 times smaller than references now available from NIST.

IMPACT

At the proposed funding level, NIST will generate the following outputs:

- **Nanodevices**:
  - Develop two new standard reference materials for semiconductor, lab-on-a-chip, and other nanotechnologies
  - Develop new quantitative measurement methods for analysis of physical and chemical properties of industrial nanoscale devices such as semiconductors
  - Publish one paper per year on the development of measurement methods, standard reference materials, and calibration systems.

- **Nanomanipulation**:
  - Develop standards for autonomous atom assembly.
  - Develop modeling and simulation programs for condensed phases, including solutions, surfaces, solids, and interfaces
  - Publish one paper per year on the development of manipulation and modeling data, algorithms, and related research.

- **Nanocharacterization:**
  - Develop three new standard reference materials for calibration and quality assurance of commercial analysis laboratories and instruments.
  - Develop several 3-D measurement methods for the analysis of physical and chemical at or near atomic spatial resolution.
  - Publish one paper per year on the development of measurement methods and standard reference materials.

- **Nanomagnetics:**
  - Develop stability and kinetics measurement systems and standard data for magnetic thin films.
  - Develop two new standard reference materials.
  - Publish one NIST paper per year and two university partnership papers per year on the measurements and standard reference materials for magnetic data storage.

Only a few examples of nanotechnology commercialization are apparent today. These are the semiconductor and magnetic data storage industries. Both these industries are helping the U.S. to be competitive in world markets and can lead to general conclusions about the impact of nanotechnology as it enters more market sectors in the 21st century.

The standards and measurements developed at NIST will continue to help U.S. industry maintain and improve leadership of the $200 billion computer and peripheral market, which will be increasingly dependent on nanotechnology. Most of the U.S. electronics manufacturing supplier infrastructure firms are small. For example, of the 192 member companies of SEMI/SEMATECH, 109 have annual sales of $10 million or less and 161 have annual sales of $100 million or less. As the large semiconductor firms move rapidly toward nanodimensions, these small businesses will constantly be under pressure to catch-up. NIST will provide these firms with the measurements and standards infrastructure that will allow them to maintain their high technology edge.

Giant Magnetoresistance (GMR) is a nanoscale effect that was discovered approximately 10 years ago and now dominates the $35 billion U.S. magnetic data storage industry. Companies that did not invest in GMR technology early in its development have been left behind in the rapidly changing, highly competitive information technology storage market. With declining hard disk market share, NIST must provide the measurement infrastructure to help keep U.S. industry strong. Standards are not only important for manufacturing, but also for commerce. Most manufacturers assemble their drives from heads, disks, motors, suspensions, and electronics made by other companies. NIST must play its historical role of minimizing disputes between buyers and sellers through impartial standards to maintain international commerce.

This initiative is designed to broadly benefit most sectors of the U.S. economy through new innovations in nanotechnology, which is a critical enabler for information technology, manufacturing, health care, defense applications, automotive, communications, plastics, and many other economic sectors. This initiative is designed to improve U.S. leadership in the $400 billion telecommunications industry and improve U.S. share in the $35 billion magnetic data storage technology.

In the United States, over 14 percent of GDP is related to expenses associated with the treatment of chronic illness and acute care. Currently, there are over 100 million Americans with chronic illness, including heart disease, arthritis, diabetes, depression, asthma, and Alzheimer's disease. Chronic illness, which correlates to aging, accounts for at least 70 percent of hospital admissions and half of all emergency room visits. The U.S. population is aging rapidly. Today, every eight seconds a baby boomer turns fifty, totaling 11,000 fiftieth birthdays every day. Projections are that by the year 2020 17 percent of the American population will be over the age of 65, significantly increasing the incidence of chronic illness and associated health care costs. Nanotechnology will greatly impact the efficiency and availability of advanced health care diagnostics and treatments to U.S. citizens. Nanosensors, "lab-on-a-chip" diagnostic systems, and nanoimplants will replace many currently expensive technologies with higher quality, lower cost nanotechnologies. NIST will develop the measurements and standards necessary to allow industry to design, manufacture, and assure the quality of these devices.

Because nanotechnology is in its initial stages of discovery and growth, many effects cannot be imagined let alone accurately predicted. The Interagency Working Group on Nanotechnology predicts that this technology will have a major effect on every industrial sector. This new technology area requires a large infrastructure to aid rapid U.S. commercialization of new discoveries. A major portion of that infrastructure is NIST-based measurements and standards that industry must use to see if and how well their products work.

CONGRESSIONAL BUDGET INITIATIVE PROPOSAL FY 2001 – UNFUNDED

TITLE: Optical Technology

DIVISIONS: All Physics Laboratory Divisions and the Optoelectronics Division of the Electronics and Electrical Engineering Laboratory

OBJECTIVE

To provide measurements and standards critical for private sector development of advanced optical technologies, including applications in communications, information technology, health care, advanced manufacturing, remote sensing, and other areas. These measurements and standards are needed to ensure U.S. economic and technical leadership in key fields increasingly driven by advances in optics and optoelectronics. These efforts support the DoC goals of preparing our communities for a technology-based society by building vital optical telecommunications and networking support and promoting electronic commerce through improving network efficiency and interoperability. This initiative also supports the White House priority for information technology R&D in the area of advanced networking.

The U.S. optoelectronics industry has identified several key areas where NIST measurements and standards are required to enhance U.S. competitiveness and support future technology. This initiative will focus on developing measurement and standards in several of these key areas: optical fiber; optical waveguide devices; sources, including lasers and LEDs; optoelectronic modules, including transmitters, receivers, and amplifiers; optoelectronics in computing; optical storage; and imaging. NIST's newly created Office of Optoelectronic Programs will work closely with industry to coordinate NIST's work in these areas. The initiative includes funding to build partnerships with U.S. universities to help develop the measurements and standards technology needed by U.S. industry and science.

PROBLEM MAGNITUDE AND NIST ROLE

Optics will be a primary driver of technology advances in the next century, just as electronics transformed the economy and technology of the 20th century. Optics is a critical enabling technology directly responsible for at least $50 billion in annual U.S. commerce. The $400 billion U.S. telecommunications industry relies increasingly on optical fiber networks. Optical technology supports a rapidly growing share of the Nation's $120 billion annual shipments in computer equipment and peripherals. The Internet is a fundamental part of our economic and information infrastructure, and future generations of the Internet will depend on optical data transmission for fast and reliable networking. Manufacturing of an enormous range of products depends on accurate optical measurements of size, quality, temperature, and other key factors. A wide variety of lasers have become ubiquitous in our economy and technology, from the commonplace (retail price scanners, CD players, long distance telecommunications, and hardening polymer dental fillings) to the exotic (reshaping of corneas to correct vision defects, rapid sequencing and study of DNA, creation of new forms of matter and atom lasers, and developing ways to use atoms for computations not possible with even the most powerful electronic computers). These applications of optics will expand in importance and new uses for optical technology will be created.

Measurements and standards underpin existing and future applications of optics. Optical technology is particularly measurement intensive, as light has many critical properties such as wavelength, power, polarization, interaction with materials, and quantum properties that must be accurately characterized. NIST measurements and standards have already proven crucial to providing a competitive advantage to the U.S. fiber optic industry. As optical technology applications grow and diversify, U.S. industry will require more measurement support from NIST.

Only NIST has both the missions to support industry and the necessary combination of staff expertise, industry contacts, and worldwide recognition as the leading measurement and standards institution. NIST's fundamental mission is to support U.S. industry with the measurements, standards, and technology needed to ensure continued economic growth. U.S. industry recognizes NIST's key role in supporting technology development. For example, the Optoelectronics Industry Development Association (OIDA), the largest trade organization in the $10 billion U.S. optoelectronics components industry, identifies metrology as one of the four areas of manufacturing infrastructure most in need of improvement. In the 1998 report "Metrology for Optoelectronics," the OIDA lists 35 specific recommendations for NIST to develop new measurements and standards needed to help the industry become more competitive and productive.

NIST works closely with optical technology industry groups such as OIDA and the Council for Optical Radiation Measurements (CORM) to determine the most important measurement and research services needed by U.S. industry to support technology development. Current limited resources allow NIST to meet only a few of the Nation's top optical measurement priorities. This initiative will enable NIST to provide a much broader range of measurement and research services. NIST's new Office of Optoelectronics Programs, working closely with the optical technology industry, will ensure that NIST measurements and research are most effectively targeted to industry's greatest needs.

As world leaders in optical technology, NIST scientists and engineers have invented new techniques to measure extremely low powers of light from the x-ray to the far infrared ranges; developed world-leading frequency standards accurate to one part in one million billion (1015); pioneered the use of lasers for precise length measurements; and developed the first standards for effectively characterizing the performance of computer flat panel displays. NIST staff excel at research and development for future optical technology measurements. NIST staff have also won the Nobel Prize in Physics for development of laser cooling and trapping techniques; created for the first time a new state of matter (the Bose-Einstein condensate) in which large numbers of atoms act as a single giant molecule; pioneered applications of atom optics in which lasers are used to manipulate atoms with incredible precision; demonstrated the first true atom laser; and demonstrated quantum computing using the interaction of light and atoms to potentially make enormously complex calculations. NIST is uniquely positioned to respond to industry's need for improved optical measurements, standards, and underpinning measurement research. The recently published National Research Council report "Harnessing Light" identified optics as a "critical enabling technology" and specifically stated that "NIST should support development of optical metrology" and called on the government to "recognize the dramatic new opportunities in fundamental research in atomic, molecular, and quantum optics and ... encourage support for research in these areas."

NIST will leverage its resources through research and development partnerships with major university optical technology programs. In some areas of optical technology, partnerships with universities can provide needed research and development more cost-effectively than starting new programs at NIST that duplicate technology and expertise already present at universities. Such partnerships also strengthen collaborations between NIST, universities, and industry to the benefit of the Nation.

PROPOSED NIST TECHNICAL PROGRAM

NIST will develop the required measurements, standards, and facilities to enable U.S. industry to develop and apply optical technology in support of the U.S. optoelectronics industry. Optoelectronics is the marriage of optical and electronic components to produce critical technologies used in telecommunications, the Internet, laser printers, fax machines, retail scanning systems, CD and DVD information storage systems, laptop computer displays, laser surgical treatment, sensor systems to control manufacturing, and many other technologies.

NIST will develop new measurement techniques and standards to support U.S. industry in seven key areas identified by the Optoelectronics Industry Development Association report. Specific programs to be coordinated through NIST's Office of Optoelectronic Programs will include:

- Measurements and standards to support wavelength division multiplexing (WDM), an optical telecommunications technique permitting simultaneous operation of enormous numbers of optical data channels in a single fiber. NIST will develop required new metrology for practical wavelength and frequency standards, bandwidth measurements, precise dispersion measurements, ultra-sensitive measurement of polarization, non-linear properties, and characterization of new transmission components.

- Measurement techniques for information transmission rates of up to one trillion bits per second, a 100-fold increase over existing levels.
- Development of protocols and test-beds to ensure fast, reliable, and efficient exchange of information over optical networks.
- Development of improved network timing and synchronization methods to ensure interoperability between different networks.
- Measurements and standards to support advanced applications of lasers in medicine, including corneal reshaping for vision correction, repair of diseased or damaged retinas, photodynamic cancer therapy, and other health care applications.
- Improved measurements and standards for flat panel displays and other advanced displays.
- Measurements and standards for inexpensive blue lasers, enhanced optical resolution techniques, and the extension of disc-based storage methods to multiple layers.
- Measurements and standards for measuring the performance of light-emitting diodes used in a wide variety of applications.

NIST's Office of Optoelectronics Programs will work closely with major universities to determine which programs or parts of programs are best realized through partnerships and which should be conducted intramurally. Twenty-five percent of the initiative resources will be used to build NIST-university partnerships.

IMPACT

This initiative is designed to broadly benefit large sectors of the U.S. economy through improving the use of optical technology, a critical enabler for information technology, manufacturing, health care, defense applications, and many other economic sectors. At the proposed funding level, this initiative will generate the following outcomes:

- Improve U.S. share in the $40 billion global optoelectronics component market through measurements and standards support, already proven successful in the optic fiber sub-sector of the optoelectronics industry.
- Support U.S. leadership in the $400 billion telecommunications industry, which increasingly relies on optical technology.
- Improve U.S. share in the optical technology portion of the $200 billion computer and peripheral market, increasingly dependent on optical technology for data storage and networking.
- Promote U.S. leadership in electronic commerce through advanced networking standards and measurements, expected to grow to $300 billion per year by 2002.
- Build the foundation for future technology advances in telecommunications, computing, health care, manufacturing and other fields by developing measurements and standards science to support future developments and needs.

The measurements and standards developed in this initiative will directly benefit the optoelectronics industry and users of optoelectronics components, the information technology industry, the optics and optical instrument industry, and a broad range of manufacturers using optical measurements in process control and/or assessing product quality. Improved optical technology and measurements will also have significant impact on large sectors of the economy such as health care, manufacturing, and defense applications.

Annual U.S. sales of optoelectronics components and related equipment and related industry surpass $40 billion, directly supporting more than 150,000 employees distributed across 30 states. The U.S. has been very successful in optoelectronics components for telecommunications (thanks largely to a concerted effort of industry and NIST to provide fiber optic standards), but much less successful in other areas of optoelectronics. The new NIST measurements and standards programs will help the U.S. optoelectronics industry substantially improve its current 25 percent global market share.

Metrology is particularly important to productivity, competitiveness, and innovation in optoelectronics. The OIDA notes that for production of optical fiber and related components -- the one area of optoelectronics where the U.S. leads -- "the development of better measurements at lower cost has been essential to both manufacturing and market development ... This was achieved through the cooperation of manufacturers and users of fiber, working ... closely with instrument manufacturers and NIST ... The success of optical fiber metrology must be replicated in other parts of the optoelectronics industry if other market segments are to be successfully developed."

At the recent annual compound growth rate of 15 percent to 20 percent for optoelectronics components sales, global markets will double in about four years, compared to sales of semiconductor electronic components which are increasing at about 10 percent annually. The optoelectronic component market leverages much larger economic sectors, including information technology (telecommunications, computers, and related markets with $680 billion combined sales per year). NIST measurements and standards will help U.S. industry increase market share in this highly-competitive global market.

NIST measurements and standards for optical components and next generation networking will strongly support the U.S. information technology sector, which has grown from about 4 percent of the total U.S. economy in the mid-1970s to about 8.2 percent in 1998. Internet-based electronic commerce is projected to exceed $300 billion by 2002. According to the Forrester Group, the volume of on-line commerce between businesses is expected to grow from $8 billion in 1997 to over $300 billion within the next four years. For example, improving interoperability of electronic data exchange among the automotive supply industry is expected to save $1.1 billion annually.

COMPETENCE PROPOSALS FY 2001+

**The NIST Quantum Information Program*

D. Wineland (847), E. Cornell (848), W. Phillips and P. Julienne (842), and C. Clark (841)

Study of Membrane Proteins Isolated in Synthetic Nanostructures

L. Ratliff (842), with J. Woodward (Chemical Science and Technology Laboratory)

Biomolecular Nanotechnology and Single Molecule Biophysical Probes

L. Goldner and J. Hwang (844), with J. Hubbard, D. Burden, G. Poirier, and R. Mountain (Chemical Science and Technology Laboratory)

Nanocrystal Photonics

S. Brown (844) and G. Bryant (842), with B. Bauer (Materials Science and Technology Laboratory) and A. Gaigalas (Chemical Science and Technology Laboratory)

Radiatively Participating Media in Non-Contact Thermometry and Industrial Simulations

B. Tsai (844), with L. Blevins, A. Hamins, K. McGrattan, and J. Widmann (Building and Fire Research Laboratory) and P. Chu (Chemical Science and Technology Laboratory)

Ultracold Neutron Production and Transport

P. Huffman (846), with H. Chen-Mayer (Chemical Science and Technology Laboratory)

Liposome-Encapsulated Alpha-Emitters for Radiotherapy and Imaging

L. Karam and B Zimmerman (846), with L. Locascio (Chemical Science and Technology Laboratory)

+ Proposed for initiation in FY 2001
* Funded and initiated in FY 2001 (October 2000)

FY 2001 NEW COMPETENCE PROJECT

(Initiated in October 2000)

TITLE: The NIST Quantum Information Program

PRINCIPAL INVESTIGATORS: D. Wineland (847), E. Cornell (848), W. Phillips and P. Julienne (842), and C. Clark (841), with colleagues from the Information Technology Laboratory

SUMMARY

The goal of this program is to build an experimental prototype (10 qubit) quantum logic device. Success will provide the basis for: metrology at the Heisenberg or quantum limit (as opposed to the shot noise limit), physically secure communication, and revolutionary paradigms in information and computing for the 21st century.

TECHNICAL STRATEGY

Our effort will focus on using two-level atomic systems for qubits. These qubit systems have small decoherence, are capable of entanglement which is a necessary requirement for a quantum gate, and provide the best near term prospect for success. Use of atomic systems will be pursued on two broad fronts, with the Ion Storage Group focussing on trapped-ion technology, and the Laser Cooling and Trapping and JILA Atomic Physics Groups developing neutral-atom optical systems.

The primary challenge is to construct a logic device that meets the criteria for a quantum processor: state preparation, scalability, two-qubit gates or entangling operations, efficient readout, and small decoherence. The two approaches proposed have different strengths with respect to these criteria. Controlling decoherence even in these "natural qubit" systems is a technical chalenge since we must maintain an ability to interface with the processor while simultaneously providing a benign environment that prevents decoherence. Controlling this decoherence while scaling the system is necessary to build a high-fidelity processor with "on demand" two-bit quantum gates.

The immediate objectives of the trapped-ion work are to overcome the effects of motional heating (which degrades the fidelity of the data-bus qubit) and to multiplex ion-trap systems by transferring ions (quantum information) between processor arrays. The latter goal is essential to scalability in the ion implementation while the former addresses the requirement for small decoherence.

The neutral-atom program will test possible implementations of quantum logic operations in optically-confined systems. Near-term technical objectives include: uniform loading of optical lattice sites with a predetermined number of atoms, addressing of the individual qubits in an optical lattice, and entanglement of atoms in lattice sites. The primary difficulty of the neutral-atom approach is addressibility and efficient readout.

The theoretical effort focuses on providing detailed modeling of current experimental systems, identifying fundamental limitations due to effects of noise and decoherence, and evaluating alternative approaches for implementing quantum logic in trapped-atom systems, such as lithographically-produced optical, magnetic, and patterned waveguides. In response to recent suggestions made by colleagues in industry, we will also investigate prospective applications of devices with less than 10 qubits in collaboration with academic and industrial theoretical computer scientists.

EXPECTATIONS

The goal is to construct an experimental prototype (~ 10 qubit) quantum logic device, capable of entangling all the qubits via "on demand" entanglement of any two qubits. The prototype device will provide a testbed for: encoding stabilized quantum memory, demonstrating quantum error correction, implementing fault-tolerant quantum gates, testing a loss-tolerant quantum repeater for a quantum information network, and implementing optimal quantum strategies for precision measurements.

This project has increasingly valuable payoffs with increasing levels of risk. Success in developing metrological applications below the shot-noise limit is very likely and can provide for further improvement in time and frequency standards in the near term. A quantum information network has higher risks but a greater potential impact on secure communications; and quantum computing has potentially revolutionary impact on an increasingly technical society. In this regard the program is well designed to provide likely successes while leveraging the higher risk goals of quantum computing that require larger numbers of qubits and greater fidelity.

IMPACT

NIST is well positioned to have world leadership in the emerging area of quantum information and its physical implementation since the program builds on existing world class expertise in manipulating ions and neutral atoms. Success in this endeavor has potentially revolutionary impact on secure communication, information technology, and measurement science - all areas that are relevant to NIST mission. Industrial representatives at the March 3, NIST-Industry meeting on quantum information technology concluded that NIST needs to serve as a leader and stimulator in this area since the research remains too risky for companies. NIST leadership will help to insure that U.S. companies remain both informed and at a competitive advantage in this area.

This program also builds on the Physics Laboratory's long term goal of creating the basis for metrology of quantum systems where the component part of the system consists of one or a few atoms in an extended sea or environment. This type of metrology will become increasingly important as nanotechnology moves from the submicron limit to the 1 nm to 10 nm scale.

FUNDAMENTAL CONSTANTS DATA CENTER

OVERVIEW

The FCDC supports the NIST mission by:

- providing an international information center on the fundamental constants;
- periodically providing sets of recommended values of the constants for international use;
- administering the NIST Precision Measurement Grant (PMG) Program;
- providing the editorship of the *Journal of Research of the National Institute of Standards and Technology*; and
- interpreting the International System of Units (SI) for the United States.

PROGRAM DIRECTIONS

■ **Information Center and Constants Adjustments.** Maintain a fundamental constants library, a Web bibliographic database, respond to inquiries, and carry out the next Committee on Data for Science and Technology (CODATA) least-squares adjustment of the values of the constants.

■ **Precision Measurement Grants.** Continue to fund proposals of the highest quality and that provide maximum benefit to NIST.

■ **Fundamental Constants Theory.** Create an atomic theory bibliographic database and do calculations where needed for the theory used in evaluation of the fundamental constants.

■ **SI Units.** Generate and disseminate publications related to the SI.

■ **Measurement Uncertainty.** Under the auspices of the international Joint Committee for Guides on Metrology (JCGM), generate guides on expressing measurement uncertainty.

MAJOR TECHNICAL HIGHLIGHTS

■ **Constants Wall Chart and Wallet Cards.** Concurrent with the NIST centennial, thousands of copies of a wall chart and a wallet card giving subsets of the 1998 CODATA recommended values of the fundamental constants of physics and chemistry (the most current) were distributed to physicists, chemists, other scientists, engineers, and students throughout the world.

■ **Centennial Issue of NIST Journal of Research.** To commemorate the NBS/NIST centennial on March 3, 2001, the January-February 2001 issue (Vol. 106, No. 1) of the *Journal of Research of the National Institute of Standards and Technology* was published as the Centennial Issue under the title "NBS/NIST — 100 Years of Measurement." The 370 page issue contains 12 articles, all centered on measurement recognizing that since its founding in 1901, NBS/NIST has served as the Nation's National Metrology Institute (NMI). Indeed, metrology has been the foundation upon which the institution has rested for the first 100 years of its existence. The Centennial Issue is available on the Web at http://www.nist.gov/jres.

■ **Theory of the Hydrogen Atom.** Precise theoretical predictions of the properties of hydrogen are important, not only to test our understanding of this basic atom, but also to provide information on the fundamental physical constants, such as the Rydberg constant. Over the past several years, a NIST-led project has carried out a precise computation of the most basic quantum electrodynamic (QED) effect in the spectrum of hydrogen, namely the radiative process in which the atom emits and then reabsorbs a photon (the quantum of electromagnetic radiation). This process results in shifts of the atomic energy levels, which, in turn, determines the frequencies of light that are emitted and absorbed in experiments. The calculation was carried out for the 1S, 2S, and 2P states of hydrogen. By employing intensive, high-performance parallel computation, with CPU times of the order of months, the project has led to a reduction of the uncertainty in the one-photon QED effect by over three orders of magnitude. This work was the result of a collaboration between NIST and the Technical University of Dresden, Germany, and is described as a "spectacular success" in Phys. Reports, **342**, 63 (2001).

■ **New Publication on the SI.** The 2001 Edition of NIST Special Publication (SP) 330, *The International System of Units (SI)* is now available. It is the U.S. version of the English text of the seventh edition (the most recent) of the definitive international reference on the SI, the modern metric system, published in 1998 by the International Bureau of Weights and Measures (BIPM) under the title *Le Système International d'Unités (SI)*. However, the 2001 Edition of SP 330 also incorporates the contents of *Supplément 2000: additions et corrections à la 7e édition (1998)* published by the BIPM in June 2000. The 2001 edition of SP 330 replaces its immediate predecessor, the 1991 edition, which was based on the sixth edition of the BIPM SI publication.

■ **New Precision Measurement Grants**. Two new NIST Precision Measurement Grants have been awarded. One was made to Prof. Mohideen of the University of California at Riverside for the project entitled "Precision Measurements of the Casimir Force Using an Atomic Force Microscope." The aim of the research supported by this grant is to make high precision measurements of the Casimir force between small metallic objects. The Casimir force is the result of the effect that the objects have on the electromagnetic fluctuations in the vacuum in the space between them. This force can be significant at distances less than 100 nm, and so it plays an important role in the mechanical properties of artificial microstructures. The proposed research will increase the precision of measurements of the Casimir force by over a factor of 10,000 and will measure the temperature dependence of the force.

The other grant was made to Prof. Schoelkopf of Yale University for the project entitled "Development of an Electron-Counting Ammeter." The aim of the research supported by this grant is to make a device to measure electric current (an ammeter) based on measurement of the frequency of voltage oscillations across a tunnel junction that allows only one electron at a time to pass through. Such a device could only measure small currents, however a sufficient number in parallel could measure a current that would be large enough to allow fundamental tests of present day resistance and voltage standards based on quantum devices. An electron-counting ammeter is more likely to be scalable to such a use than the analogous single electron pumps which already exist. ❑

OFFICE OF ELECTRONIC COMMERCE IN SCIENTIFIC AND ENGINEERING DATA

OVERVIEW

The Office of ECSED supports the NIST mission by coordinating and facilitating the electronic dissemination of Physics Laboratory (PL) information, and by developing methods and serving as a model for the effective dissemination of scientific and engineering data by means of computer networks.

PROGRAM DIRECTIONS

■ **WWW Dissemination of Information.** This Office is responsible for PL world wide web (WWW) pages at physics.nist.gov. We produce material for WWW publication, encourage and support the production of material by others, and assure the high quality of disseminated information. We are also engaged with PL Divisions and the NIST Standard Reference Data Program in developing physical reference databases for WWW dissemination. We design and develop effective WWW database interfaces to facilitate access to the data.

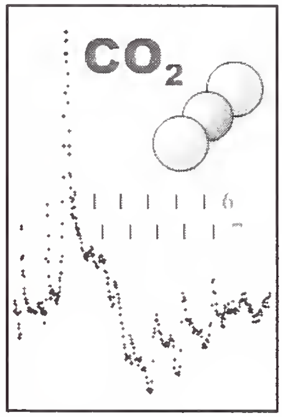
We began providing information to the public in June 1994. We provide a wide array of information ranging from physical reference data to staff and organization lists, technical activities, publication lists, research and calibration facilities, and news and general interest items. In a recent month, there were over 900,000 requests for web pages from the Gaithersburg server (over half from our databases), and nearly 6 million requests for web pages from all Physics Laboratory servers (including Boulder and time.gov).

MAJOR TECHNICAL HIGHLIGHTS

■ **New "Look and Feel" for PL's Web Pages.** The entire PL website has been and will continue to be modified to comply with legally enforced accessibility standards for the disabled as required by Section 508 of the Rehabilitation Act of 1973 and the Workforce Investment Act of 1998. These modifications will allow those with sight disabilities to easily navigate and obtain information from our website. In addition, all of the top level pages (including Division pages and some Group pages) have been redesigned with a new graphical interface in order to meet the "One Face of NIST" criteria. This design change will continue as pages are added or updated. (G. Wiersma, K. Olsen, and R. Dragoset)

■ **Units Markup Language (UnitsML).** This Office has started a collaboration with Lawrence Berkeley National Laboratory and EEEL to develop an XML (eXtensible Markup Language) schema for encoding measurement units and uncertainty in XML. Adoption of this schema will allow for the unambiguous exchange of numerical data over the World Wide Web. In addition, we will be collaborating with ITL to create a NIST registry containing SI and non-SI unit information. (R. Dragoset and B. Taylor, with M. McLay [EEEL])

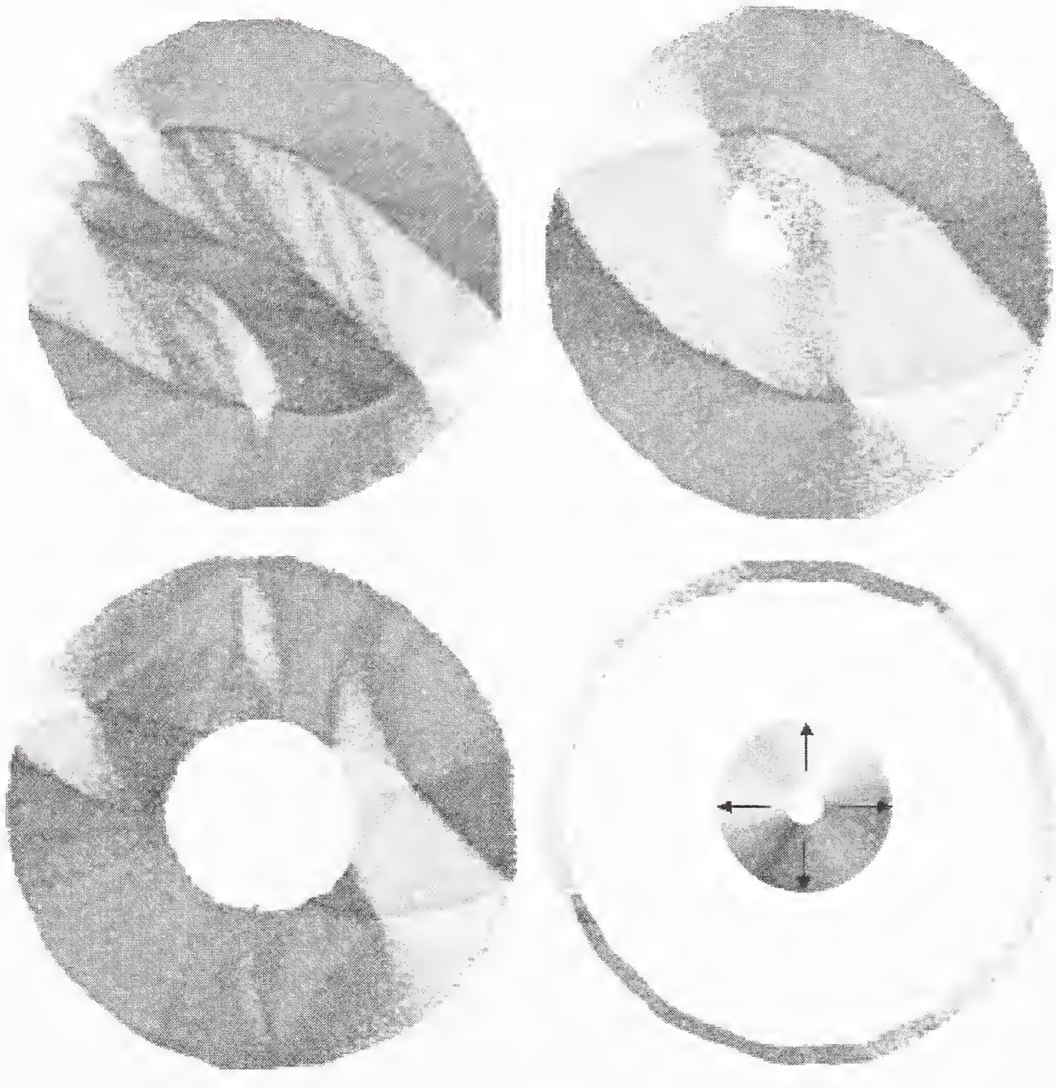
■ **Photoionization of CO_2 Database.** The study of CO_2 photoionization has historically attracted much attention due to the importance of the ionization of CO_2 in the photophysics of planetary atmospheres, including the Earth's atmosphere. Additionally, CO_2 is an integral part of the carbon cycle for plant life and, as a consequence, the photochemistry and photophysics of this molecule has been the subject of considerable interest by a number of scientists over the last several decades. In collaboration with the Optical Technology Division, the vibrational branching ratios and asymmetry parameters in the photoionization of CO_2 in the region between 650 Å and 840 Å have been made available in an online database [physics.nist.gov/CO2]. (D. Schwab, R. Dragoset, and A. Parr)



■ **Diatomic Calculations: Equations and Theory.** In collaboration with the Optical Technology Division, NBS Monograph 115, "The Calculation of Rotational Energy Levels and Rotational Line Intensities in Diatomic Molecules" (June 1970), a frequently referenced document, has now been made available on the web. Procedures are described in this pedagogical monograph for making quantum mechanical calculations of rotational energy levels and rotational line intensities in diatomic molecules [physics.nist.gov/DiatomicCalculations]. (G. Wiersma and J. Hougen)

■ **Database Updates.** In collaboration with the Atomic Physics Division, two online databases were updated: (i) the Electron-Impact Ionization Cross Section Database (new theoretical data along with relevant references were added for the following ions: H_3O^+, CH_2^+, CH_3^+, CH_4^+, $C_2H_2^+$, $C_2H_4^+$, and $C_2H_6^+$) [physics.nist.gov/ionxsec]; and (ii) the Searchable Bibliography on the Constants (288 entries were added) [physics.nist.gov/constantsbib]. (A. Kishore, K. Olsen, Y.-K. Kim, G. Wiersma, and P. Mohr). □

ELECTRON AND OPTICAL PHYSICS DIVISION



Overleaf

SEMPA images: SEMPA images of the magnetization in patterned Fe thin-film discs and rings. The rings are ten micrometers in diameter and the magnetizations direction are mapped into color as given by the colorwheel.

ELECTRON AND OPTICAL PHYSICS DIVISION

OVERVIEW

The Electron and Optical Physics Division supports the NIST mission by developing measurement capabilities needed by emerging electronic and optical technologies, particularly those required for submicrometer fabrication and analysis. In particular, the Division:

• fabricates nanostructures and develops measurement techniques for determining their electronic and magnetic properties. A key facility supporting this work is the Nanoscale Physics Laboratory (NPL), described below, which was brought online in July 2000, after several years of design and construction. The core tool of the NPL is a cryogenic scanning tunneling microscope (STM), designed and built within the Division, which has picometer spatial resolution and can operate in magnetic fields as high as 10 Tesla. Another key measurement capability of long standing within the Division is scanning electron microscopy with polarization analysis (SEMPA), which provides submicrometer resolution of magnetic structures via analysis of the spins of ejected electrons. Our SEMPA laboratory was upgraded this year with a new field-emission scanning electron microscope that can attain 10 nm spatial resolution, the highest available anywhere. This capability underpins the Division's drive to develop metrology for the next generation of magnetic data storage devices.

• provides the central national basis for absolute radiometry in the deep-ultraviolet (DUV) 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 Synchrotron Ultraviolet Radiation Facility (SURF III), which provides a dedicated source of radiation over this spectral range. As an absolutely calculable source, SURF III is being developed as the primary national standard of source-based radiometry from the EUV through the infrared spectral regions. It also supports a range of research activities by members of the Division, other NIST organizational units, and external customers.

• develops metrology and fabrication capabilities for EUV optical components and systems. EUV optics, which deal with "light" of 10 nm wavelength, are favored for possible application in next-generation semiconductor lithography. The Division works closely with the leading industrial efforts in this field. In July 2000, we took delivery of a 5000 kg vacuum chamber, housing a reflectometer capable of measuring the massive (45 kg) mirrors that will be used in an alpha-tool EUV stepper. This chamber was connected to the Division's SURF III synchrotron radiation source in December 2000, and performed its first mirror measurements in the Spring of 2001. By virtue of its operating wavelength, EUV Optics is intrinsically a nanoscale technical discipline. It requires nanometer accuracy of optical figures over macroscopic dimensions, and fabrication of multilayer structures with near-atomic sharpness of interfaces. During the past decade, the Division has developed a range of metrologies for use by the EUV optics community, and has provided NIST calibration services for EUV optical components used in lithography, solar and stellar astronomy, synchrotron radiation research, and EUV laser sources.

PROGRAM DIRECTIONS

The Division applies 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 5 nm to 250 nm wavelength range; and delivering quality measurement, calibration, and secondary standards services in the 5 nm to 250 nm wavelength range.

In pursuit of these activities, 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 optical measurement services and research efforts of the Division and those of other NIST organizational units and external customers. A higher level of performance was attained by systematic improvement of the RF and fuzz power control systems, and by increased logging and automatic control of operational parameters. These have greatly improved the reproducibility of operating conditions, so that, for example, injection of 700 mA is now routine (the 300 mA beam current for SURF II could not be obtained with any reliability). In addition, considerable improvements in beam stability have been made, sufficient to justify the establishment of a Fourier-transform spectroscopy beamline.

The Scanning Electron Microscopy with Polarization Analysis (SEMPA) Facility utilizes spin polarization analysis of secondary electrons to image magnetic structure of surfaces and thin films. It has been used to analyze device structure for many major firms in the data storage industry, to develop standard reference materials for magnetic metrology, and to identify the basic mechanisms of exchange coupling that underpin the performance of giant magnetoresistive (GMR) devices. In 2001, a new high-resolution field emission scanning electron microscope began operation in this facility to enable studies of magnetic domain structure at 10 nm spatial resolution.

■ **Measurement and Calibration Services.** The Division's activities in calibration and measurement services are centered around SURF III. We maintain a dedicated spectrometer calibration beamline on BL-2, which mainly supports NASA programs in solar physics and EUV astronomy. During 2000 it provided calibrations of instrumentation destined for the NASA TIMED satellite mission, and it also enabled stability studies on new photodiodes that are candidate components for space-qualified detector packages. A DUV radiometry facility, operated by the Optical Technology Division, is located on BL-4. This facility incorporates an absolute cryogenic radiometer, a NIST primary standard for detector-based radiometry, which allows for intercomparison with the primary source-based standard, SURF III. An EUV optics calibration facility has been in long service on BL-7, 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. An upgrade of this facility began in Autumn 2000, with the commissioning of a new large-chamber reflectometer that can accommodate the coming generation of EUV stepper mirrors. During 2001, this reflectometer successfully completed tests on sample mirrors produced by EUV-LLC, and we believe it to be the most accurate instrument of its type in the world. Our UV and EUV detector transfer standards program uses a dedicated beamline on BL-9 to supply calibrated photodiodes to external customers within the framework of the NIST Calibration Services Program. Its activities in 2001 in this regard are summarized in the Appendix. In addition, BL-9 supports custom measurement work associated with the development of new photodetectors.

■ **Basic Research.** The Division's basic research programs focus on issues that bear on the development of nanoscale metrology. In 2001, the Nanoscale Physics Laboratory began its first experiments, on the effects of magnetic impurities on electronic structure (the Kondo effect) and spin-dependent electron tunneling into superconductors. The first demonstrations were made of the ability to build nanostructures by moving individual cobalt atoms into predetermined positions on a copper surface. The new SEMPA facility provided the first images of the domain structures of mesoscopic ring magnets, revealing domain-wall structures that had not been inferred from previous studies. The mechanism of current-induced magnetization reversal in thin magnetic films was elucidated by theoretical studies. Progress was made toward manipulating individual atoms in magneto-optical traps, and a new research program began the study of ultracold atoms in optical lattices as a candidate system for quantum information processing. Theoretical simulation of Bose-Einstein condensate dynamics revealed a simple effect in the expansion of a rotating condensate that provides a definitive signature of superfluidity; this prediction was quickly confirmed by experiment. Electronic structure calculations were instrumental in revealing birefringence in CaF at

157 nm, an effect that has important consequences for the design of deep-ultraviolet optical lithography systems.

MAJOR TECHNICAL HIGHLIGHTS

■ **Manipulating Magnetic Impurities**. Researchers in the Electron Physics Group (EPG) have recently demonstrated the capability of manipulating individual cobalt atoms on a copper (111) surface (see fig. 1) and measuring their electronic properties on an individual-atom basis. This work is part of a study of the physics of magnetic impurities in non-magnetic host materials. Building magnetic nanostructures atom-by-atom allows EPG researchers to study the fundamental beginnings of magnetism at the nanometer level.

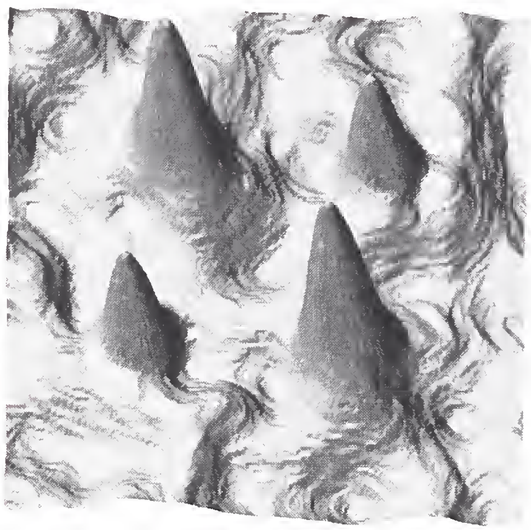


Figure 1. Rendered STM image of two cobalt monomers and two cobalt dimers on a Cu(111) surface. The image is 8 nm × 8 nm and was recorded at a temperature of 2.3 K and a tunneling current of 50 pA with a sample bias of –20 mV.

A single magnetic impurity atom embedded in a non-magnetic host material represents the smallest magnetic structure and gives rise to the rich physics of the Kondo effect. At temperatures below the so-called Kondo temperature, the host conduction electrons condense into a many-body ground state that collectively screens the local spin of the magnetic impurity. This screening cloud displays a set of low-energy excitations at the Fermi-level known as the Kondo resonance.

Atomically resolved measurements of the Kondo resonance are being performed on single magnetic impurities using a cryogenic scanning tunneling microscope system that is part of the Nanoscale Physics Facility in the Electron Physics Group. Building higher order magnetic clusters is achieved using atomic manipulation techniques being developed as part of the Nanoscale Physics Facility. Figure 1 shows a rendered scanning tunneling microscope (STM) image of the two cobalt monomers and two cobalt dimers (blue) that were positioned to form a square nanostructure pattern. The atomic manipulation was performed by forming a tunable chemical bond between the STM tip and the cobalt atoms, and then dragging them one-by-one to the desired location on the copper surface. The separate cobalt atoms in the dimers are not resolved, but appear higher than the cobalt monomers. The modulation in the copper-colored surface shows the quantum mechanical interference pattern resulting from the scattering of the quasi 2--dimensional electrons at the copper (111) surface off the cobalt atoms. The cobalt atoms are a magnetic impurity in the copper system and give rise to the Kondo effect. Future measurements concentrate on the dependence of the Kondo resonance on magnetic field and the interaction between magnetic atoms. (J.A. Stroscio, E.W. Hudson, R.J. Celotta, A.P. Fein, and S.R. Blankenship)

■ **Insight into Magnetic Coupling through Antiferromagnets**. The study of magnetic coupling between two ferromagnetic films separated by a non-ferromagnetic metallic spacer has been an extremely active and fruitful area of research over the last decade. The interlayer exchange coupling, which causes the magnetization of the two ferromagnetic layers to be parallel or antiparallel to each other depending on the thickness of the spacer, is now well understood when the spacer is a diamagnetic or paramagnetic metal. However, when the spacer layer is an antiferromagnet, such as Mn, the observed coupling is non-collinear. J. Slonczewski (IBM, Yorktown Heights) proposed the *torsion model* to describe the more complicated interlayer coupling when exchange coupling within the antiferromagnetic spacer is important. The torsion model predicts that the coupling angle between the ferromagnetic layers is 90° for rough interfaces. For sufficiently smooth interfaces, the torsion model predicts that the coupling angle between the ferromagnetic layers will vary around a mean value of 90° by an amount that is very sensitive to the width of the thickness distribution of the spacer layer. We have performed scanning tunneling microscopy measurements of the growth of Mn on nearly perfect Fe single-crystal whisker surfaces to determine the thickness distribution of the Mn layer for particular growth conditions. The coupling angles actually measured for Fe/Mn/Fe(001) tri-layers, using scanning electron microscopy with polarization analysis (SEMPA), were in approximate agreement with the predictions of the torsion model. Scanning tunneling microscopy measurements of the lateral scale of the Mn thickness distribution provided insight into how to go beyond the torsion model to obtain a better explanation of the SEMPA results. (D. Pierce)

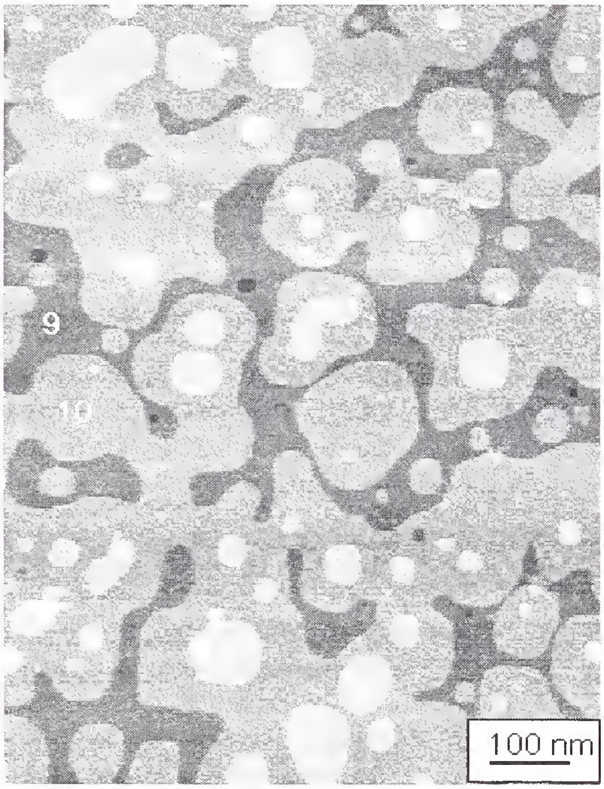


Figure 2. STM image of Mn film on an Fe whisker substrate. Mn regions that are 9, 10, and 11 atomic layers thick are indicated. Such STM images were used to determine Mn thickness distributions and quantitatively test the torsion model of magnetic coupling through antiferromagnets.

■ **SEMPA Images of Mesoscopic Ring Magnets.** In collaboration with the University of Cambridge Thin Film Magnetism Group, we have used the NIST Scanning Electron Microscopy with Polarization Analysis (SEMPA) facility to directly image the magnetic domain structure of mesoscopic ring magnets. The micrometer sized rings and discs, patterned out of Co thin films, are the basis for new types of nonvolatile, magnetic random access memories. The SEMPA measurements provided the first images of various magnetic structures in these patterned films. Some of the magnetic structures agreed with predictions based on earlier non-spatially-resolved magnetization measurements of these films, but additional, unexpected domain wall structures were also observed. Knowledge about the nanoscale magnetic structure of the various magnetic states and how the states switch from one to another is a critical part of determining whether these patterned magnetic structures will make useful magnetic memories. (J. Unguris and T. Monchesky)

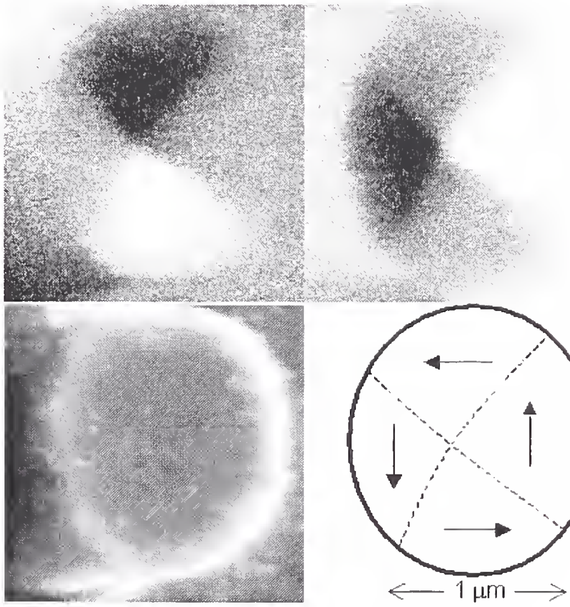


Figure 3. SEMPA image of a circular Co pad showing the two orthogonal in-plane magnetization components (top), the topographic image (bottom), and a schematic of the magnetic domain structure.

■ **Symmetry Properties of the Intrinsic Birefringence of Calcium Fluoride** Advanced microcircuit fabrication is now performed using DUV lithography for the pattern-forming step. The industry roadmap calls for a progression of DUV laser sources, from Kr:F 248 nm and Ar:F 193 nm lasers to the F_2 157 nm laser as the critical dimension shrinks according to Moore's law. Presently, calcium fluoride is the material of choice for the 157 nm lithography stepper.

To achieve diffraction-limited imaging, the combined stepper optics must have a very low value of integrated birefringence. Calcium fluoride is a crystal of cubic symmetry that was known to be practically optically isotropic for long wavelength light. Much to the surprise of the developers of DUV lithography, a NIST experiment performed in the Atomic Physics Division showed that an unacceptable level of birefringence develops in the DUV. In a collaborative theoretical effort with the Optical Technology Division, the experimental results were corroborated and the symmetry properties of the birefringence elucidated.

The magnitude of the difference of the index of refraction for the two orthogonal polarizations for each propagation direction is shown in figure 4. At the largest, it is over one part per million – over ten times larger than the specification required for diffraction-limited imaging. Such a value has forced the developers of DUV lithography to reconsider their designs of 157 nm lithography systems. Solutions include trying to cancel the anisotropy by orienting different lenses in different directions, additional reliance on reflective optics, and the use of a mixed barium calcium fluoride. (Z.H. Levine, J.H. Burnett, and E.L. Shirley)

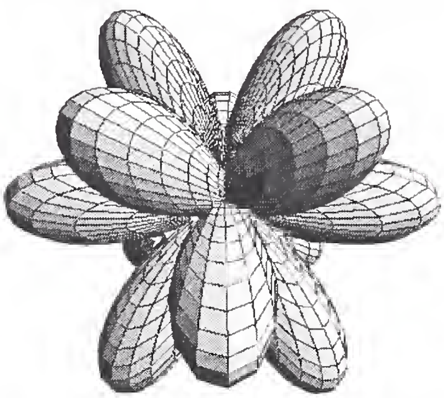


Figure 4. The magnitude of the difference of the index of refraction for the two polarizations for various directions of propagation. There are maxima along the 12 equivalent [110] directions and zeroes along the 14 equivalent [001] and [111] directions. Hence, there are seven optic axes in this system, in contrast to the permitted values of 1, 2, and infinity in standard crystal optics. A VRML version of this figure appears at physics.nist.gov/ duvbirefring.

■ **Superfluid-to-solid crossover in a rotating Bose-Einstein condensate.** At ultralow temperatures, a dilute gas of atoms can form a new state of matter: a Bose-Einstein condensate (BEC). When a trapped BEC is subjected to rotation, it cannot rotate as a whole due to its superfluid nature; rather, a few isolated quantized vortex lines are formed within the system. As the angular frequency increases, a larger number of vortices penetrate the sample and the cloud begins to expand in the plane perpendicular to the axis of rotation. At very high frequencies, the vortices arrange themselves into highly regular triangular arrays reminiscent of vortex lattices in superconductors. Figure 5 depicts the results of numerical simulations of this behavior, obtained by solving the Gross-Pitaevski equation. BEC densities are shown perpendicular (upper row) and parallel (lower row) to the axis of rotation for two sets of data with increasing rotational frequencies. This work was motivated by experiments at JILA, which, as of the time of this report, have not yielded resolved images of the vortex structures. However, the aspect ratio of the condensate density profile obtained in these calculations is in good agreement with that found in the JILA experiments. (D. Feder and C. Clark)

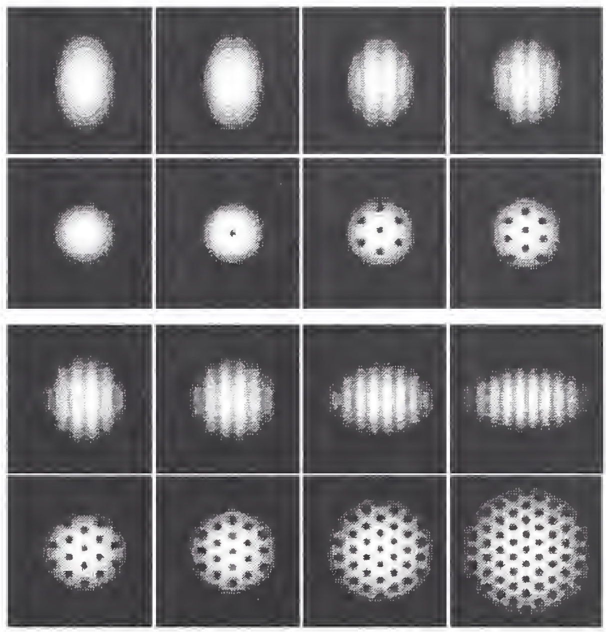


Figure 5: Vortices in a trapped rotating Bose-Einstein condensate.

■ **NIST Beowolf System On-Line.** The Bureau of the Census, a sister agency of NIST in the Department of Commerce, established over 600 local census offices across the United States to process forms for the 2000 U.S. Census. When this job was completed, the computer equipment from the local census offices was surplused and made available to other agencies at no cost. In collaboration with the Atomic Physics and Optical Technology Divisions, we have constructed a 128-node parallel computer using some of this equipment. Each node is a Pentium II computer with a 350 MHz or 450 MHz processor and from 128 MB to 768 MB of RAM. The 128 nodes are configured as a parallel machine using the Linux operating system with the Beowulf software environment originally developed at NASA in the mid-1990s – hence the name: NIST Beowulf System (NBS). The NBS cluster is located in the former control room of the NIST Linear Accelerator, which has ample air-cooling and electrical power capacity, in the basement of the Radiation Physics Building adjacent to the SURF synchrotron facility. It is currently engaged in parallel simulations of the dynamics of quantum gases and ultracold atomic collisions. (C. Clark, M. Edwards, D. Feder, W. George, E. Shirley, C. Williams)

■ **Spontaneous Coherent Microwave Emission at SURF III.** Following the long-established theory of synchrotron radiation emission, all radiation is emitted in harmonics of the frequency of the accelerating radio-frequency field. Researchers in the Physics Laboratory have made this "picket-fence" structure visible at SURF III, for microwave radiation emitted at frequencies around 10 GHz, which corresponds to the 100^{th} harmonic. This microwave radiation was easily detectable due to its coherent enhancement by a "sawtooth" or longitudinal bunch instability in the electron beam. A collaborative study of this phenomenon with researchers from the Argonne National Laboratory's Advanced Photon Source was reported in the May issue of the journal *Physical Review Special Topics – Accelerators and Beams*. The major breakthrough in this study was the identification of the connection between spontaneous coherent synchrotron radiation emission, micro-bunching, intensity noise in the visible spectral range, and the sawtooth instability, which has long been known to affect SURF under certain operating conditions. This greater understanding of SURF III beam dynamics has contributed to significant improvements in beam stability that have been obtained recently. (U. Arp, T. Lucatorto, K. Harkay, N. Sereno, and K.J. Kim)

■ **SURF Operations.** Steady improvement in SURF operational conditions was seen in 2001. Injection currents of 700 mA are now attained routinely and reliably, compared to the 500 mA that was ordinarily attained in 2000 and the 200 mA that was characteristic of SURF II. These improvements are due to the continuation of the high-quality experimental accelerator physics program that was initiated at SURF in 2000, and in particular to attention given this year to control of the RF power system. In the early stages of this program, an analysis of the power spectrum of the RF cavity showed substantial power in high harmonics of the 114 MHz fundamental frequency due to complex beam-cavity interactions. The harmonic structure was associated with intensity and spatial noise in the beam, and it was highly sensitive to operating conditions. High harmonics have been suppressed by filters, but it is desirable to retain flexibility to control the power in the 3^{rd} and 5^{th} harmonics. A Mach-Zehnder-type interferometer was designed, constructed, and installed in the RF system to give us direct control over these harmonics. This has enhanced the stability of the beam, and studies are underway to identify the optimal power and phase distributions in the fundamental and harmonic frequencies.

A first attempt to put higher power into the RF cavity, in June 2001, resulted in electrical breakdown in a vacuum feedthrough, which actually melted the input electrode. This had the potential for a loss of SURF service for several months or longer, which would have been tremendously disruptive because it occurred at a time of peak user demand. However the ingenuity and tremendous effort put forth by the SURF operational staff solved the problem in a few weeks.

Demand by NASA for calibration services on SURF BL-2 remained high, with several instruments being calibrated for forthcoming rocket and satellite missions. The Division was saddened by the unexpected death of Rossie Graves in January 2001. Rossie, an electronics technician, was a stalwart of the SURF operations team, a dedicated and happy worker, and a friend to all. He was recognized this year by posthumous receipt of the Judson P. French Award, and will be long remembered by his colleagues (U. Arp, L. Deng, A. Farrell, E. Fein, M. Furst, R. Graves [deceased 2001], E. Hagley, L. Hughey [retired 2001])

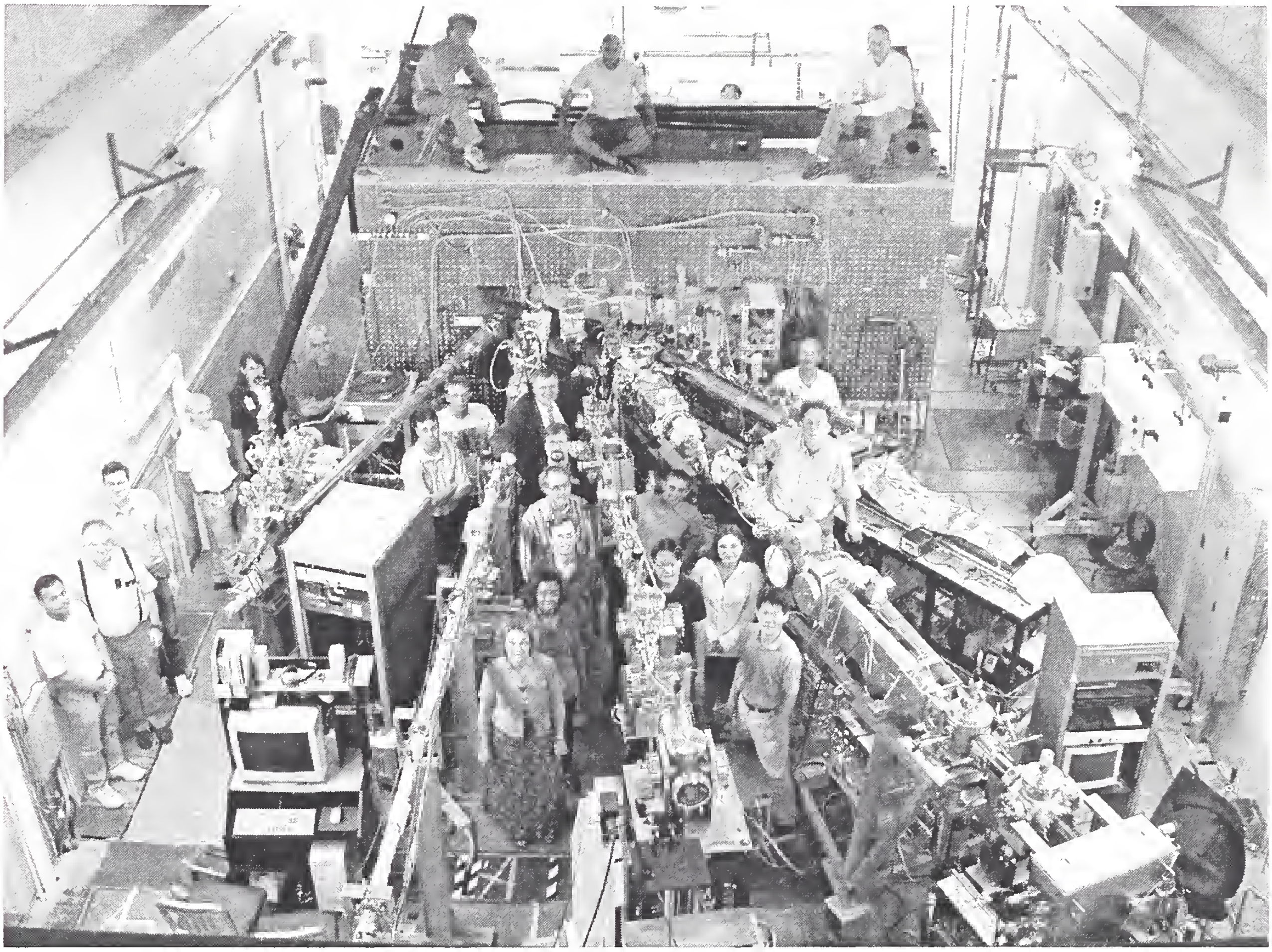
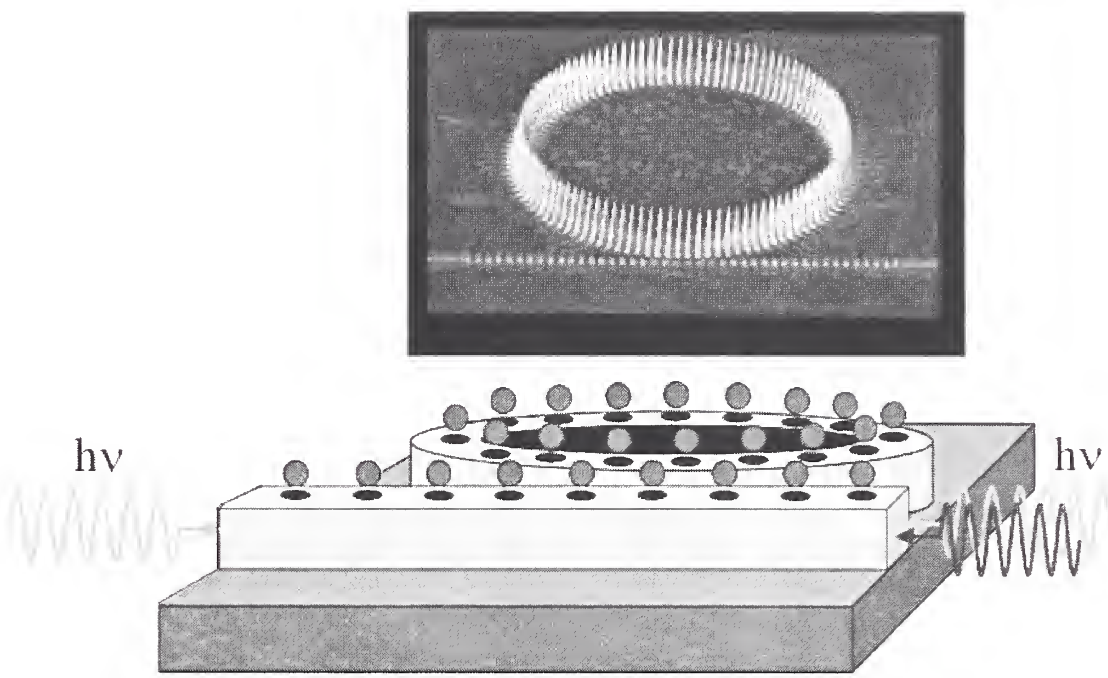


Figure 5: SURF operations team, support staff, and users, in the beam hall, August 9, 2001. □

ATOMIC PHYSICS DIVISION



Overleaf

Device for Trapping Atoms for Quantum Processing Applications: The figure shows the evanescent field of a linear waveguide and ring resonator that can be used for trapping and guiding atoms with possible applications to quantum information. The device consists of a low index glass substrate that has a linear waveguide and a 10 μm diameter ring resonator built out of a higher index glass material on top of the substrate. The top picture shows the buildup of the evanescent field above the surface of the waveguide structure, showing the strong enhancement of the field in the ring resonator. The bottom schematic shows atoms trapped above the surface of the waveguide and ring resonator in localized potentials formed by the standing wave light patterns in the waveguide structures. The atoms can be moved by changing the relative phase of the counter-propagating light beams.

ATOMIC PHYSICS DIVISION

OVERVIEW

The Atomic Physics Division carries out a broad range of experimental and theoretical research in support of emerging technologies, industrial needs, and national science programs. This work is tied closely to the NIST core mission to develop and promote measurement, standards, and technology. Specifically, the division:

- undertakes experimental and theoretical research on quantum processes in atomic (both neutral and ionized), molecular, and nanoscale systems; and it explores atomic interactions in plasmas and with surfaces;
- advances the physics of laser cooling and electromagnetic trapping and the optical manipulation of neutral atoms using Bose condensates and optical lattices and applies these techniques to develop the field of quantum information processing;
- provides measurements, standards, and atomic reference data for specific generic needs in various industrial and scientific applications such as the processing of materials by plasmas and ion beams, commercial and residential lighting, properties of optical materials, x-ray analysis of thin films, and fusion plasma diagnostics; and
- 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.

PROGRAM DIRECTIONS

■ **Research on Atomic Properties.** We are continuing to use our unique ultra-high resolution Fourier transform spectrometer (FTS) for measurements of spectra of importance for microlithography, lighting industry research, and space astronomy. With our new capability of an extended ultraviolet response we are attacking problems of wavelength calibration of ArF lasers being used for microlithography at 193 nm.

As part of our ongoing Cooperative Research and Development Agreement (CRADA) with the Electric Power Research Institute (EPRI), the FTS is also being used to measure wavelengths and transition probabilities of spectra of rare earth elements that are used as additives in high-intensity discharge lamps. As part of this CRADA we are also utilizing the Advanced Photon Source at the Argonne National Laboratory to map the spatial distribution of emitters in high intensity discharge (HID) lamps by means of x-ray absorption and fluorescence measurements. HID lamps are often made with translucent envelopes, and it is not possible to obtain this information by conventional optical methods

On the theoretical side, we are continuing to calculate cross sections for the excitation and ionization of atoms and molecules by electron impact. These cross sections are used in plasma processing of semiconductors and in modeling of tokamak plasmas. New scaling methods are being developed to convert atomic excitation cross sections calculated from simple collision theories into high quality data comparable to the exact solutions that can be obtained for the hydrogen atom.

■ **Compilations of Atomic Properties.** Data centers on atomic spectra located in the Division are the principal resources for such atomic reference data in the world. We are continuing critical evaluations and compilations of wavelengths, atomic energy levels, and transition probabilities. The critical assessments benefit from the experience our scientists have gained through original research and the data that have been obtained in our own laboratory. The compilations are disseminated through published papers and databases on the World Wide Web, as for example the online interactive Atomic Spectroscopic Database, which is queried about 60,000 times per month by outside users, including many technology companies.

■ **Properties of Nanoscale Systems.** Quantum mechanical and electromagnetic methods are being developed and applied for calculating the electronic and optical properties of quantum nanostructures and for modeling the optics of nanoscale objects.

Such systems have a wide variety of technological applications, including semiconductor lasers and advanced semiconductor devices. Applications of nano-optics modeling include scanning near field optical microscopy for use in nanometer-scale optical metrology, single molecule spectroscopy and optical nanostructures for novel uses in atom trapping, quantum information and intradevice optical communications.

Also, an experimental activity to generate and characterize novel types of nanoscale fractures on surfaces is underway at the Electron Beam Ion Trap (EBIT) facility. Here, we are using STM, AFM, and photoluminescence techniques to characterize the response of surfaces to highly charged ion beams. In order to understand the formation and decay of the "hollow atoms" that underlie the production of the nanoscale features, we are using x-ray spectroscopy to observe the surfaces during ion bombardment, in collaboration with the University of Paris, Harvard University, and the University of Stockholm.

■ **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 (BECs). We are investigating the coherent transport of condensate atoms confined in a one-dimensional optical lattice. We are also investigating the formation of molecules from BEC atoms using photo-association techniques. Comprehensive, predictive theoretical models are being developed and tested to understand the experimental results and guide further investigations.

■ **Quantum Information.** We are investigating the feasibility of using ultracold neutral atoms in optical lattices for quantum information studies. The conceptual starting point for such studies is a three-dimensional optical lattice with one atom per lattice site, in the ground vibrational state. Such a system will serve as an initialized register for quantum information processing. In a recently constructed apparatus generating Bose-Einstein condensates of rubidium atoms, we are investigating the adiabatic loading of the atoms into the ground state of the optical lattice as well as the loading of one atom per lattice site. The latter should be achieved through a Mott-insulator transition. We will investigate the factors influencing the decoherence of atoms in the optical lattice, which will determine the fidelity of this system for quantum information processing. By introducing well characterized noise, such as laser intensity noise, we can study decoherence in a controlled manner. In a parallel theoretical effort we are developing models and running simulations of the atoms in an optical lattice in order to understand the experimental results and determine the best strategy for achieving the highest fidelity possible.

■ **Optical Manipulation of Biological Objects.** We are developing techniques for the remote manipulation and control of biological objects. We use lasers to trap cells and microspheres coated with biochemical molecules in order to study biomolecular interactions. We are investigating the use of lasers for manipulation of liposomes as subnanoliter reaction vessels. We are using laser-trapping techniques to bring two liposomes, each encapsulating some biochemical molecules of interest, into contact. A focused UV laser beam is used to remove the interstitial lipid bilayer membranes, allowing the contents of the liposomes to mix and a biochemical reaction to take place. This elementary sequence applied to a sample of liposomes containing a variety of biochemical molecules will allow us to perform combinatorial chemistry with very small quantities of reagents. Applications of these investigations include genetic testing, pharmaceutical development and targeted drug delivery.

■ **Optical Properties of VUV Materials.** Using the unique VUV phase-shifting Twyman-Green interferometer and VUV polarimetry facilities that we developed, we study VUV optical properties, such as stress-induced birefringence, intrinsic birefringence, and index homogeneity of materials important for VUV optics. These *at-wavelength* measurement capabilities, not presently available to the industry, are recognized as critical for 157 nm photolithography. With the help of these facilities we are also working on solving the intrinsic birefringence problem in 157 nm lens materials that we first pointed out. We are developing, in collaboration with crystal production companies, mixed crystals such as $Ca_{1-x}Ba_xF_2$ and $Ca_{1-x}Sr_xF_2$ that we calculate will have no intrinsic birefringence.

■ **X-Ray and Gamma-ray Measurements.** We use crystal diffraction to study the properties of x- and gamma-ray radiation. For measurements requiring high precision, flat diffraction crystals of known lattice spacing are employed in both reflection (Bragg) and transmission (Laue) geometries. The thrusts of this program are x- and γ-ray wavelength standards, material properties at x- and γ-ray wavelengths, and the determination of neutron binding energies. For lower-precision measurements, curved crystals with position-sensitive detectors are used. This program will assist spectral studies of highly-ionized species at the NIST EBIT, the calibration of medical radiographic x-ray sources, and x-ray diagnostics for laser fusion plasmas. For the latter, to characterize the hot electron energy distribution of such plasmas, we are designing, fabricating, assembling, and calibrating a cluster of five curved crystal x-ray spectrometers which will be packaged together in one diagnostic module and deployed at the National Ignition Facility at Lawrence Livermore National Laboratory.

■ **High Resolution X-Ray Probes of Thin-Film Electronic Structures.** The sub-nanometer wavelengths of x-ray probes and their relatively weak interactions with materials make them a nearly ideal means for determining the geometry of the thin film and multilayer structures that underlie modern semiconductor manufacturing. We are developing an advanced metrological capability in this area including high performance instrumentation and advanced forms of modeling and analysis. Also, we are establishing a new industrial consortium (the Consortium for High-resolution x-ray Calibration Strategies) to better address the long term needs of users of high resolution x-ray scattering instrumentation in the semiconductor industry, with the core task to deliver NIST-documented prototype calibration samples to consortium members in a timely manner.

■ **Optical and X-Ray interferometry.** We are carrying out intercomparisons of Michelson and Fabyry-Perot interferometry for displacement measurements and observe the effect of diffraction on interferometric measurements. We will also use our expertise to apply advanced interferometric techniques to important problems for which they are well suited. One such project concerns measurement of the coefficient of thermal expansion for low-thermal-expansion materials using Fabry-Perot interferometry, a matter of critical importance to next-generation EUV lithography.

MAJOR TECHNICAL HIGHLIGHTS

■ **Radiometry of Hg/Ar Discharges for Lighting Applications.** Lighting accounts for about 40% of all electrical power consumed in the commercial sector. About 60% of this power is used in fluorescent lamps; thus even small improvements in these lamps have large potential for energy and cost savings. Newly evolving fluorescent lamp designs operate with Hg/Ar discharges at higher current densities and lower Ar pressures than conventional lamps. As part of a lighting research consortium organized by the Electric Power Research Institute (EPRI), we have made systematic studies of the radiant output of such discharges for all significant lines of neutral mercury in the ultraviolet and visible regions of the spectrum. For this task we constructed a special lamp that permits variation of the discharge parameters over a wide range of operating conditions. Of particular importance is the output at 254 nm, which is efficiently converted to visible light by the lamp phosphor, and the output at 185 nm, which is less efficiently converted and damages the phosphor, shortening its life. Our studies have revealed large variations in the relative strength of these lines with changes in current density and Hg pressure (see fig. 1).

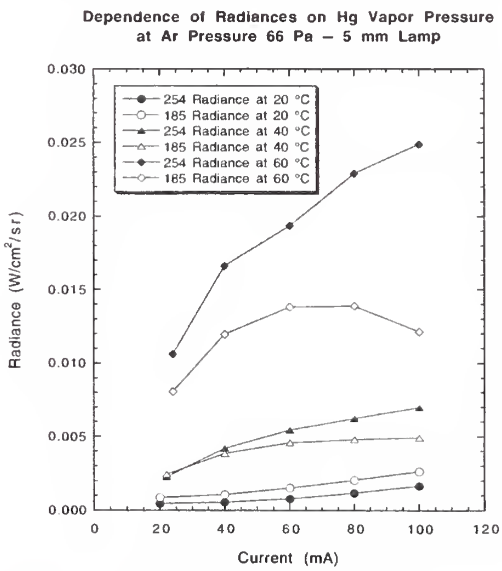


Figure 1. Relative radiances of the 185 nm and 254 nm lines of neutral Hg in discharges at low Ar buffer gas pressure show large variations with lamp current and Hg vapor pressure as determined by the 20°C, 40°C, or 60°C temperature of the Hg cold spot.

These results have major implications for improving the efficiency of fluorescent lamps. Our data are now being used for detailed comparisons with predictions of computer lamp models by collaborating scientists at U. Wisconsin and Osram/Sylvania. (C.J. Sansonetti, J. Curry, and J. Reader)

■ **Spectral Data for Fusion Research.** To provide data for spectra of moderately charged ions of interest for the diagnostics of edge regions of tokamak plasmas, we have carried out a new analysis of the spectrum of three-times-ionized niobium, Nb^{3+}. Niobium is a highly refractory material that may play a role in the design of armor plates for future tokamaks. For this analysis high-resolution spectra of Nb in the 30 nm to 400 nm region were observed with our 10 m vacuum spectrographs. The analysis was performed with the aid of atomic structure codes that calculate the expected energy levels and relative intensities in this region. All missing levels of the lower configurations were located and other configurations newly determined. By using our high-resolution Fourier transform spectrometer (FTS), we have also carried out high-precision measurements of spectra of the rare gases neon, krypton, and xenon in the infrared. These gases are used to blanket the tokamak divertor regions in order to reduce the heat load on the first walls. Previously, only calculated wavelengths were available for these spectra. The observations resolve many questions in the existing descriptions of these spectra and will be of great use for the diagnostics of a wide variety of plasmas. (J. Reader, E.B. Saloman, and C.J. Sansonetti)

■ **High Resolution Spectroscopy for Space Astronomy.** Precise atomic spectral data are needed to interpret stellar spectra from high-resolution spectrometers on the Hubble Space Telescope. To address this need, we have made high-precision measurements of wavelengths and hyperfine structure parameters for a large number of lines of holmium and for selected lines of lead and bismuth. Determination of the abundances of heavy elements in chemically-peculiar stars depends critically on the availability and accuracy of these laboratory data. Our high-resolution FTS was used to measure wave numbers and hyperfine structure (hfs) constants for approximately 1800 lines of Ho I and Ho II between 300 nm and 1200 nm. HFS constants were determined for 300 levels of Ho I and 90 levels of Ho II. The spectra of Bi I, Bi II and Bi III, which lie at wavelengths too short for the FTS, were measured with our 10 m normal-incidence vacuum spectrograph. The wavelength of a ^{207}Pb IV line at 130 nm was also measured with this spectrograph. As the hfs of this line was too small to be resolved in the observed spectrum, we devised a scheme to obtain an accurate estimate of it from the hfs of an analogous line in ^{199}Hg II, which had been measured by the NIST ion storage group in Boulder. The lead and bismuth results have been used to determine the abundances of these elements in the stars chi Lupi, HR 7775 and AV 304. (G. Nave, J. Reader, and C.J. Sansonetti)

■ **Critical Compilations of Atomic Spectra.** We completed work on the Handbook of Basic Atomic Spectroscopic Data, which provides important energy level information as well as wavelengths and transition probabilities for neutral and singly ionized atoms of 99 elements. This handbook will be published in three types of media: in an electronic book (eBook) format, as a database on the Web, and as a printed publication. It will form a convenient resource for spectrochemical and other industrial applications. Also completed was a new Web database of spectral data needed for the interpretation of observations from the Chandra X-Ray Observatory. This provides critically compiled atomic transition probabilities for spectra of Ne, Mg, Si, and S in the 10 Å to 170 Å region. A compilation containing critically evaluated transition probabilities for neutral and singly ionized Ba was completed and a critical review of recent experimental data on Stark widths and shifts of neutral atoms and positive ions was prepared. (J. Fuhr, A. Robey, W.C. Martin, L. Podobedova, J. Sansonetti, and W.L. Wiese).

■ **Electron-Impact Excitation and Ionization Cross Sections.** Cross sections for excitation and ionization of atoms and molecules by electron impact are used for the modeling of plasma processing of semiconductors and plasmas in fusion devices. For atoms such as aluminum, excitation of inner-shell electrons to the valence shell leads to additional ionization, because the excited atom has an energy that is higher than the ionization energy (autoionization). It is difficult to treat this "indirect" ionization channel using conventional methods such as close-coupling or R-matrix theory. We have developed new scaling methods that provide simple, yet reliable ways to calculate cross sections for this type of indirect ionization. For example, we find that indirect ionization in the Group IIIB atoms (B, Al, Ga, In, Tl) doubles the total ionization cross section. In the case of Al, by combining the recently developed binary-encounter-Bethe (BEB) theory for direct ionization with new scaling methods for indirect ionization, we were able to explain a factor-of-two discrepancy between experiment and earlier theory, which did not take account of indirect ionization. For Ga, our new theory enabled us to choose a preferred data set between two competing sets of experimental data. The good agreement with the preferred set is shown in fig. 2. (Y.-K. Kim, M.A. Ali, and P.M. Stone)

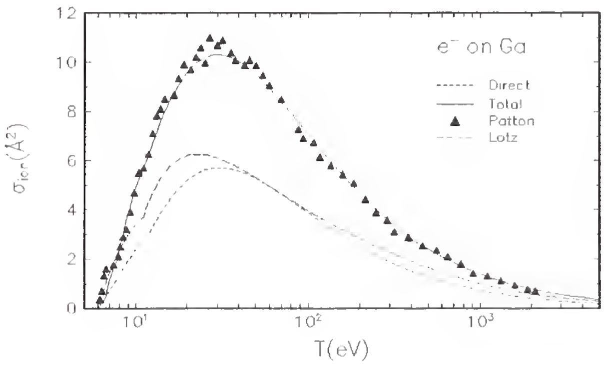


Figure 2. Comparison of theoretical and experimental data for the total ionization cross sections of gallium. The solid curve labeled "Total" represents our theoretical calculation that includes indirect ionization. It is in excellent agreement with the experiment by Patton et al., while theoretical results that do not include indirect ionization, labeled "Direct" and "Lotz," reach only about one-half of the peak value obtained from experiment.

■ **Quantum Logic Gates.** The ability to coherently manipulate quantum systems should lead to dramatic breakthroughs in quantum information processing, quantum communication, and precision measurements. The Quantum Processes Group has therefore carried out theoretical simulations to show how collisions of trapped neutral atoms in optical lattice cells may be used to create entanglement between the atoms, thereby allowing high fidelity quantum logic gate operations.

Performing entangling operations requires individual atom control, which might be achieved by loading atoms into optical lattices. The trap can localize individual atoms in unique sites to a few tens of nanometers in size, and provides control over the two-atom entangling operations. Individual trapped atoms can act as quantum bits, or qubits, by taking advantage of their internal structure - hyperfine states or long-lived resonant states - or by using the motional states that result from trapping the atoms.

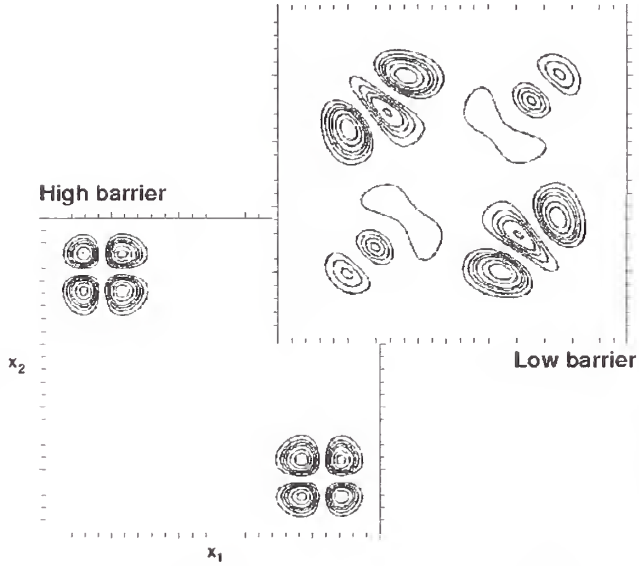


Figure 3. Contour plot of a wavefunction for two interacting atoms in a one-dimensional double well potential with a barrier between the two wells. A high barrier localizes one atom in each well, whereas a low barrier allows both atoms to occupy the same well.

Our work has characterized the robustness and speed of the entanglement process when motional states of atoms in a two-color optical lattice form the qubits and the atom-atom interaction is turned on and off by controling the two laser intensities. When the barrier separating the individual optical wells is lowered by changing the relative intensity of the two lasers, the atoms tunnel through the barrier and the atom-atom interaction entangles the qubits. Figure 3 illustrates an example of a two-atom wavefunction for the two cases when the barrier is either high or low. We have shown that by properly controlling the time-dependent laser intensities a controlled quantum interference can be used to reduce the decoherence of the entanglement process to below 0.001% and simultaneously keep the time to entangle the atoms relatively short. Without the use of the controlled quantum interference a ten times longer entangling time is needed for the same decoherence rate. Moreover, we have demonstrated that the idea of using a controlled interference is not limited to entangling operations of qubits based on neutral atoms. It should be useful for other qubit implementations as well. (E. Tiesinga, C.J. Williams, F. Mies, E. Charron)

■ **Quantum Dot Clusters.** The analogy of quantum dots (QD) and nanocrystals as artificial atoms is now well established and has driven diverse applications from integrated laser devices to biosensors and biomarkers to quantum computing. We have explored the next step, the development of nanocircuits of quantum dot nanodevices, by simulating the properties of clusters of QDs (artificial molecules and nanoarchitectures) and arrays of QDs (quantum dot solids).

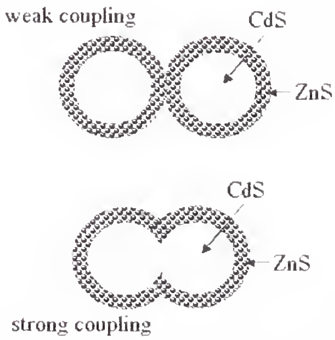


Figure 4. Schematic diagram of two interacting quantum dots with an inner core of ZnS and an outer layer of CdS. A typical dot diameter is on the order of 5 nm.

We developed previously an atomistic tight-binding simulator for the electronic and optical properties of individual QDs and nanocrystals. This past year we have extended these simulations to consider artificial molecules, quantum dot solids and nanoarchitectures. The first step was to understand simple coupled QDs, as shown in fig. 4 for two core/shell CdS/ZnS nanocrystals, and to establish the bounds for the analogy between coupled dots and artificial molecules. Coupled core/shell nanocrystals and stacked pyramidal dots grown by self-organized molecular beam epitaxy have been simulated. In each case, we have found that the conduction states in the coupled nanostructures closely follow the analogy with molecular states. Hybridized conduction states form σ and π interdot bonds. State energies and polarization depend on this bonding. Valence-state interdot-hybridization produces significant level reordering and drastic changes in oscillator strengths. Hybridization of valence states is complex and cannot be described just in analogy with molecular hybridization. (G.W. Bryant, W. Jaskolski)

■ **Cold Cesium Mysteries Solved.** Researchers in the Quantum Processes Group have solved a long-standing problem by constructing a quantitative model of collisions of ultracold cesium atoms. Atomic cesium is an important species that has been the object of numerous cooling and trapping experiments. Laser cooled cesium is also the basis of the new NIST F1 cesium atomic fountain clock. In spite of many studies, a quantitative understanding of collisions of cold cesium atoms has proved elusive. It is important to understand these collisions, since collisional shifts in the cesium transition frequency can adversely affect the performance of the fountain clock. In addition, the collisional properties of cesium atoms have prevented the achievement of Bose-Einstein condensation in cold cesium atomic gases.

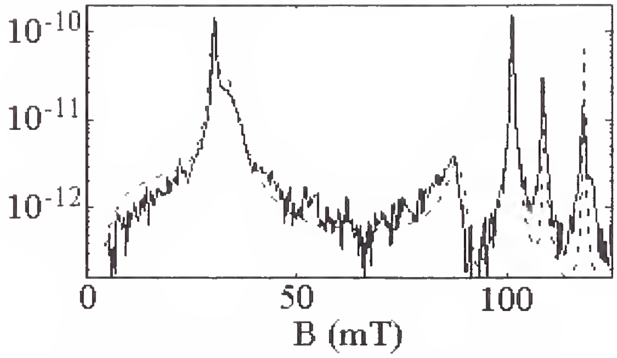


Figure 5. Inelastic collision rate constant versus magnetic field (in mT) for two cold, trapped Cs atoms in a particular ground state Zeeman sublevel.

Collisions of very cold atoms are different from normal high temperature collisions in that they are strongly affected by special quantum effects associated with the very long De Broglie wavelength of the colliding atoms. However, a collision model with only four key parameters characterizes the full quantum dynamics of cold cesium collisions. Two of these parameters are known as scattering lengths, which determine clock shifts and the stability of a Bose-Einstein condensate. One is the coefficient that gives the magnitude of the long-range force between the two atoms. The other expresses the effective interaction between the two electron spins as modified by chemical bonding effects in the cesium dimer molecule. This latter parameter strongly affects the collisional losses that hinder Bose-Einstein condensation.

The NIST group set out to explain all previously existing data on cold cesium collisions. A key to the analysis were new data provided by experiments in the group of Stephen Chu at Stanford University, which used a magnetic field to tune a number of cesium dimer bound states to be in resonance with the colliding atoms. Fitting to the Stanford data determined the four parameters. The resulting quantitative model not only accounts for all known data on ground state cold cesium atom collisions but also accurately predicted locations for a number of resonances prior to measurement.

Figure 5 compares our model calculations (dashed) with typical Stanford data (solid) on collision rate versus magnetic field. The new model, contrary to previous expectations, predicts that the collisional shift in a cesium fountain clock could be greatly reduced if the clock could be operated at a much lower temperature in the range of 50 nanokelvin. The model also makes specific predictions for what range of magnetic fields Bose-Einstein condensation of cesium might be possible. (C.J. Williams, P.S. Julienne, and P. Leo)

■ **Nano-optics.** Nano-optics is a rapidly emerging branch of optics driven by the need to control and manipulate light on the nanoscale for use in, for example, photonic devices and circuits, microscopy with nanometer resolution, and atom trapping and guiding. To fully understand the physics issues, we have simulated light fields on the nanoscale with applications to near-field scanning optical microscopy (NSOM), quantum computing and single molecule spectroscopy.

NSOM has been used intensively at NIST to obtain nanoscale resolution in optical microscopy. The key to NSOM is to place a nanoscale optical probe in the near-field of the sample. A critical challenge for NSOM metrology is to identify and quantify the mechanisms that provide contrast in NSOM images. Even the simplest samples can provide counterintuitive images that are difficult to interpret. Holes in a dielectric film appear dark in NSOM images despite the expectation that probe light would pass most easily through the holes. We have therefore simulated this case and could show that the image contrast is determined by how light is extracted from the NSOM probe rather than how the probe light propagates through the hole. The holes are dark in NSOM images because less light is extracted from the probe when the probe is above a hole. This simple but surprising explanation provides another step toward making NSOM a qualitatively and quantitatively accurate nanoscale metrology. (G.W. Bryant, A. Rahmani)

■ **EBIT Tests Remote Temperature Diagnostic.** In order to assist NASA scientists in measuring the temperature of hot plasmas, a team of scientists from NIST, the Harvard-Smithsonian Center for Astrophysics, the Naval Research Laboratory, the Observatory of Palermo (Italy), NASA Goddard Space Flight Center, MIT, and the Lawrence Berkeley National Laboratory have worked together on an experiment that took place at the NIST EBIT facility. Precisely controlled x-ray spectra from highly ionized iron and krypton atoms (16 and 26 electrons/atom removed, respectively) were produced by using an intense, monoenergetic electron beam threaded through a cryogenic ion trap. The highly ionized atoms were held at a temperature of approximately 5 million Kelvin while x-rays were measured with a prototype microcalorimeter detector of the sort being developed for future space missions. Spectra were collected with better than 6 eV resolution using a single detector that covered the broad spectral range from 10,000 eV to 500 eV. By simultaneously observing resonance lines and radiative recombination from the monoenergetic electron beam, it was possible to determine cross sections for electron impact excitation of the individual resonance lines. In field observations, the temperature is inferred from the ratio of spectral line strengths, assuming that the underlying atomic physics is calculable. But the benchmark spectra and cross sections obtained from the experiment at the NIST facility indicate that a key astrophysical temperature diagnostic is not valid. The experiment has thus stimulated work at other institutions to develop an improved diagnostic. (E. Takacs, I. Kink, and J.D. Gillaspy)

■ **Sub-millimeter Wave Spectroscopy of Etching Plasmas.** Sub-millimeter wave absorption spectroscopy has been applied to etching type plasmas for the identification and monitoring of plasma species. As semiconductor wafer-size grows and feature-size shrinks, monitoring and control of the basic plasma chemistry has become increasingly important for ensuring fidelity and performance of microelectronic devices. Sub-mm wave spectroscopy can monitor the crucial chemical species and provide the necessary feedback for understanding plasma processing. Our measurements have concentrated on the use of a backward wave oscillator (BWO) as the sub-mm wave source since this device is relatively compact and could easily be utilized in an industrial setting. We have identified chemical species found in fluorocarbon etching-type plasmas created in the inductively coupled version of the GEC RF Reference Cell. The GEC Cell creates plasmas similar to those used in commercial etching reactors, but has numerous ports for diagnostic access. Spectra from 10 molecules have been identified including feed gases (CHF_3, CF_3I), etching radicals (CF_2, CF), etching byproducts (CO, COF_2, SiO, SiF_2, SiF) and contaminants (H_2O). The diagnostic has been used to measure the dissociation of CHF_3 and the relative dependence of various species on plasma conditions. Spectral resolution of the BWO is so high that it could also be used to measure the translational gas through the Doppler broadening of the absorption line shapes. These gas temperatures are important input parameters to many plasma models since they are necessary to relate the measured gas pressure to the actual particle density in the chamber. The gas temperatures measured of several different plasma species have all been at or only slightly above room temperature (see fig. 6). (E. Benck with G. Golubyatnikov and G. Fraser, Div. 844)

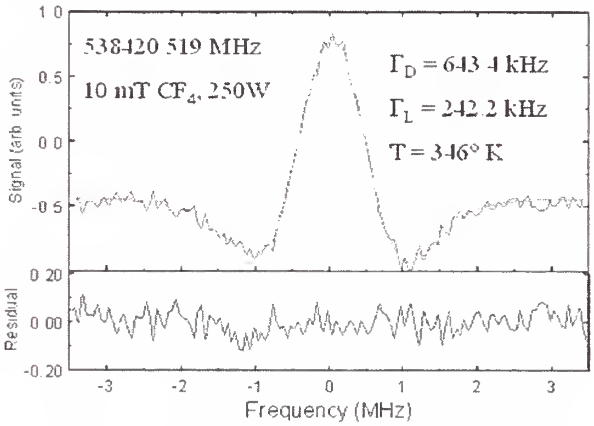


Figure 6. Second harmonic frequency modulated absorption signal of CF in a CF_4 inductively coupled discharge. The smooth curve is a line shape model fitted to the data corresponding to a gas temperature of 346°K.

UV Intrinsic Birefringence of CaF_2 and BaF_2 . We made the first measurements of an *intrinsic* birefringence in the UV materials CaF_2 and BaF_2, which are the primary optical materials considered for 157 nm optical lithography, to be used for future-generation integrated circuit fabrication. The measured birefringences are more than ten times the design tolerances for residual birefringence for 157 nm lithography systems, and all such designs will now have to be substantially modified to account for this effect. This result was unanticipated by the industry because it was assumed that the cubic symmetry of these crystals would insure isotropy of the optical properties, which in fact is only true for long wavelengths. As can be seen in the plot of our measurements below, the relatively large magnitudes of the intrinsic birefringences near 157 nm decrease rapidly to unmeasureable values in the visible, explaining why previous residual birefringence measurements of these materials in the visible did not reveal the effect. Our measurements were done in conjunction with theoretical analyses and calculations by Z. Levine (Electron Optical Physics Division) and E. Shirley (Optical Technology Division), shown by the curves in fig. 7. We first showed how the symmetry of this effect can be exploited for compensation by coupling lenses with differing crystal axis orientations. We also showed that due to the opposite sign of the effect for CaF_2 and BaF_2, it can in principale be eliminated entirely by creating appropriate mixed crystals $Ca_{1-x}Ba_xF_2$. All 157 nm systems are now being designed using at least one of these correction approaches. (J.H. Burnett)

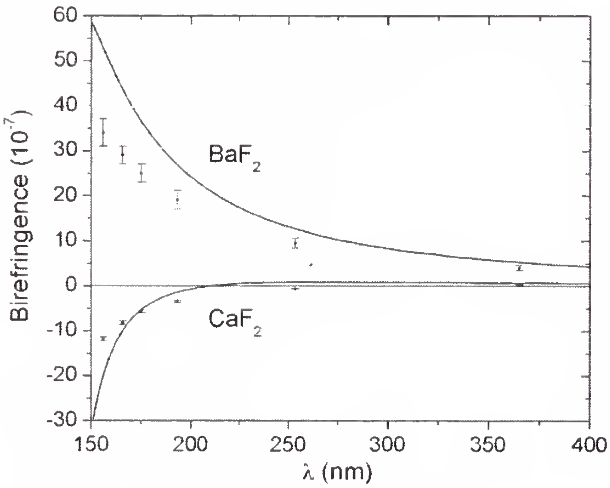


Figure 7. Measurements (symbols) and calculations (curves) of intrinsic birefringence of CaF_2 and BaF_2 as functions of wavelength (with standard uncertainties).

■ **Ultracold Collisions.** Starting with one laser to photoassociate slowly colliding atoms into bound states of excited diatomic molecules in a magneto-optical trap, we then used additional lasers to take these molecules into either doubly-excited states or to bound ground-state molecules. New spectroscopy of the uppermost bound states of the triplet ground state of Na_2 has been obtained. In addition, the production of stable ground-state molecules in a number of these states has been demonstrated and the detection of the molecules, in a state-selective manner, has been demonstrated as well. Pulsed-laser, pump-probe photoassociation experiments were carried out that show indications of the dynamics of the photoassociation-ionization process. Pairs of atoms are excited to singly-excited states with a first (pump) pulse and then to doubly-excited states that autoionize with a second (probe) pulse. In order to autoionize they must survive on the doubly-excited potential into small internuclear separations. These experiments have demonstrated the importance of the travel on the strongly attractive singly-excited molecular potentials in the dynamics of the process. Population excited to these levels at long range is able to accelerate toward smaller separations, increasing their chance of survival against spontaneous emission and also bypassing the angular momentum barriers that exist on the relatively flat ground-state and doubly-excited-state potentials. (L. deAraujo, S. Gensemer, K. Jones, and P. Lett)

■ **Ultracold Plasmas.** In an ultracold plasma produced by photoionization of a laser-cooled gas of metastable xenon we had previously measured that, at the coldest and densest parameters we could achieve, the plasma expanded with seemingly more energy than had been put in by the laser photons. In a search for a reservoir of negative (i.e., binding) energy in the form of atoms (which would assure energy conservation) we undertook an experiment that used selective field ionization to measure the formation of Rydberg atoms. We found that a substantial fraction (up to 30%) of the plasma recombines into these neutral Rydberg atoms. Summing up the binding energy in the Rydbergs did seem to account for the excess expansion energy, but these atoms were formed over a much longer time period than that of the appearance of the expansion energy. In fact, significant Rydberg formation occurred even after the plasma density dropped by 4 orders of magnitude. Based on our findings, the exact mechanism of the recombination is currently under investigation by several theoretical groups. The leading explanation is a "freezing out" of electron-ion correlations present in the plasma as it expands. We have undertaken collaborations with theoretical groups at Los Alamos National Lab and Auburn Univ. to address this problem. (M. Lim, J. Roberts, S. Rolston)

■ **Optical Tweezers.** We have observed real-time adhesion between a monoclonal antibody and its specific antigen in an experiment using optical tweezers. Both antibody and antigen molecules are immobilized on the surfaces of (different) polystyrene microspheres, which are trapped by separate optical tweezers. The monitoring of spontaneous, thermally driven, successive attachment and detachment events has allowed a direct determination of the reaction-limited detachment rate for a single bond and also for multiple bonds. A second experimental direction has been studying the use of liposomes as bioreactors. For this purpose we have set up a new experiment employing two optical-tweezer traps and an optical scalpel (a UV laser that can pierce the wall of a liposome). With this new apparatus, we are able to trap two liposomes and fuse them together, thus allowing their contents to mix. In a first experiment, we demonstrated the fusion of a dye-encapsulated liposome with another liposome and observed, with fluorescence microscopy, the mixing of the dye. (K. Helmerson, R. Kishore, and S. Kulin)

■ **Quantum Computing in Optical Lattices.** We have achieved Bose-Einstein condensation (BEC) in rubidium vapor. A new apparatus was constructed in which rubidium atoms were loaded from a Zeeman-tuned, slowed atomic beam into a magneto-optical trap (MOT) and then transferred into a magnetic trap. The atoms were then evaporatively cooled and condensed into the lowest energy state in the trap. This source of atoms will be used to load 1-D and 3-D optical lattices for investigation of different quantum logic gate designs for neutral atom quantum computing. (B. King, S. Peil, T. Porto, and S. Rolston)

■ **Optical Interactions in Bose-Einstein Condensates.** An experiment to observe "dynamical tunneling" was performed in collaboration with researchers from the University of Queensland, Australia. For a wheel spinning clockwise or counter-clockwise there is energetically no difference between the two motions, and classically to reverse the sense of rotation requires the wheel to stop. But quantum mechanics allows the system to "tunnel" from one state to another even if it is classically forbidden. Tunneling has been observed since the early days of quantum mechanics, but usually involves traversing a barrier that, classically, a particle does not have enough energy to go over. Dynamical tunneling, predicted in the early 80s, is similar, but some constant of the motion other than energy classically forbids the quantum mechanically-allowed motion. We observed classically forbidden motion of atoms transferring between two modes of oscillation in the potential wells formed by an amplitude-modulated optical standing-wave. Atoms were loaded from a BEC into the bottom of the optical potentials, and were induced to oscillate back and forth by a sudden displacement of the standing wave. The number of atoms in this particular oscillatory motion was observed to decrease with time, as a group of atoms began to appear oscillating 180° out of phase with the initial motion. Eventually, almost all of the atoms ended up in the out-of-phase motion, but then tunneled back to the initial mode of oscillation (see fig. 8). We observed up to eight coherent transfers of atoms back and forth between the two stable motions due to dynamical tunneling. No atoms were observed to exhibit motion intermediate between the two stable oscillatory motions (for example, corresponding to atoms stopping and reversing direction), providing further confirmation that the transfer of atoms was due to dynamical tunneling. (A. Browaeys, H. Haeffner, K. Helmerson, W. Hensinger, C. McKenzie, W. Phillips, S. Rolston, and B. Upcroft)

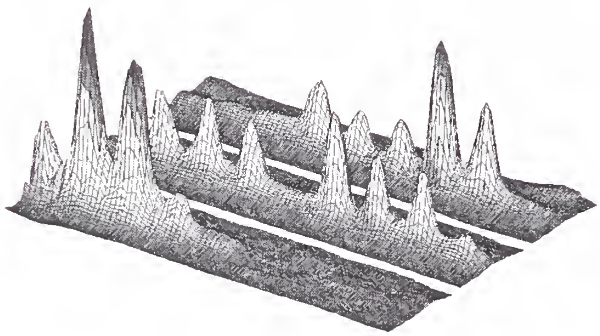


Figure 8. Dynamical tunneling in the quantum driven pendulum. The figure shows the momentum distribution of atoms released from an amplitude-modulated potential for three different times after a BEC was loaded into the potential (0.25, 2.25, and 5.25 modulation periods (f=250 kHz)). The classical result from this system would have the momentum distribution remain stationary in this stroboscopic picture. It is evident that the state of motion of the atoms is in fact oscillating back and forth, a signature of coherent dynamical tunneling. The individual peaks are separated in momentum by $2\hbar k$ which corresponds to a velocity of 6 cm/s for sodium.

■ **BEC in 1-D Lattices.** We have performed a series of experiments with a BEC in a 1-D optical lattice. Making use of the small momentum spread of a BEC and of atom optics techniques, a high level of coherent control over an artificial solid-state-like system was demonstrated. We were able to efficiently load the BEC into the lowest lattice band (and other bands) with different quasi-momentum q by varying the lattice amplitude and lattice velocity relative to the BEC. By adiabatically increasing the lattice amplitude, more than 99% of the BEC could be loaded into the lattice ground state. Such experiments are needed to evaluate the possibility of using neutral atoms in off-resonant optical lattice potentials for quantum information processing.

Using either phase or amplitude modulation of the optical lattice, we have coherently transferred population between various lattice band states. For example, we have used amplitude modulation to transfer atoms from the ground band to the second excited band for various initial q, allowing a direct measurement of the curvature of the second excited band.

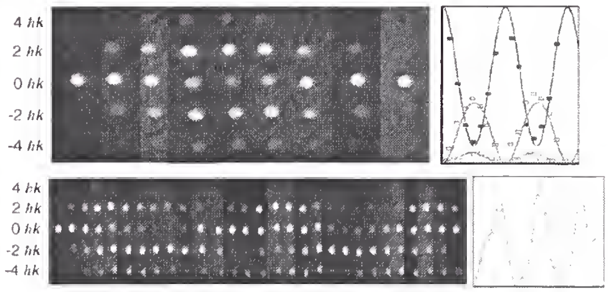


Figure 9. Time of flight images of the momentum distribution of a BEC that was suddenly loaded into an optical lattice (depth = 14 recoil energies), and held for varying lengths of time (time between each image is 0.5 microseconds). When the BEC is suddenly loaded into a lattice, the wave function is projected into a superposition of various bands. Since each band has a different energy, the relative phases evolve in time. When the lattice is switched off, the populations of the bands are projected onto plane wave states and interferences result in oscillating populations of the various diffraction orders. The top picture (simple oscillations) shows the case where quasi-momentum $q=0$ states are populated; the bottom picture depicts the case when $q=1$ states are populated by switching on a moving lattice.

We have also demonstrated a large-momentum atom beam splitter based on coherent Bragg diffraction followed by acceleration of the BEC in an accelerating optical lattice. Bragg diffraction produces atoms in a coherent superposition of 0 and

≈2 ħk, where k is the magnitude of the wavevector of the laser light. The two momentum states could be loaded predominantly into two bands of the lattice (fig. 9). Acceleration of the lattice moved atoms in one band with respect to the other, resulting in a large final momentum (we demonstrated up to 12 ħk). We have confirmed that the acceleration is coherent by constructing an atom interferometer based on this novel beam splitter. (A. Browaeys, H. Haeffner, K. Helmerson, C. McKenzie, W. Phillips, and S. Rolston)

■ **Binding Energy Measurements in Light Nuclei.** The binding energy of the neutron in several light nuclei has been measured at the Institut Laue Langevin (ILL) using the joint NIST/ILL precision gamma-ray spectrometer that is coupled to the high flux reactor of the ILL. The spectrometer measures the wavelengths of gamma-ray photons using crystals whose lattice spacings are precisely known in SI units and an angle scale that is derived from first principles. Binding energies are obtained by summing the energies (wavelengths) of all γ-rays in a cascade connecting the capture and the ground states. Binding energy measurements are important because (1) they provide high-energy (short wavelength, $\lambda \approx 0.2$ pm) standards and (2) they check the consistency of precision gamma-ray and atomic mass measurements.

Binding energy measurements have been made in ^{29}Si, ^{33}S, and ^{36}Cl species chosen because of their large capture cross sections. As an example, the reaction $n+{}^{35}\mathrm{Cl}\rightarrow{}^{36}\mathrm{Cl}+\gamma$'s leads to the relation between atomic masses and the neutron binding energy S_n, $m(\mathrm{n}) + m(^{35}\mathrm{Cl}) = m(^{36}\mathrm{Cl}) + S_n(^{36}\mathrm{Cl})$. The binding energies are ≈ 8.6 MeV and the available cascades require the measurement of γ-rays in the 5 MeV to 6 MeV range. In the course of these measurements, we have improved our capability to accurately measure small diffraction angles (< 0.1°) and pioneered the use of thicker crystals and better collimation to improve signal to background at high energies. The relative uncertainty of the binding energy measurements is 2 to 4 parts in 10^{-7} which is comparable to the relative uncertainty of the best available atomic mass differences. (E. Kessler with S. Dewey, Div. 846)

■ **Upgraded Angle Metrology for Absolute Vacuum X-Ray Wavelength Determination.** NIST's Vacuum Double Crystal Spectrometer measures absolute x-ray wavelengths from 0.6 Å to 12 Å (1 keV to 20 keV). This is tied to the SI via the lattice spacing of the diffraction crystals. The measurement of absolute wavelengths also requires accurate measurement of the angle at which the diffraction condition is satisfied. This year the crystal angle encoder was upgraded to a device that has smaller errors. Then a new general calibration approach was developed to determine the encoder error function so that even these small errors can be corrected. A twelve-sided optical polygon was used with a nulling autocollimator and the requirement of circle closure (0° = 360°) to first determine the angles between adjacent polygon faces. Then the polygon was phased with respect to the encoder, mapping out its 360° error function twelve points at a time. The fitted error function and its residuals (fit minus measurement) are shown in fig. 10 (a) and (b), respectively.

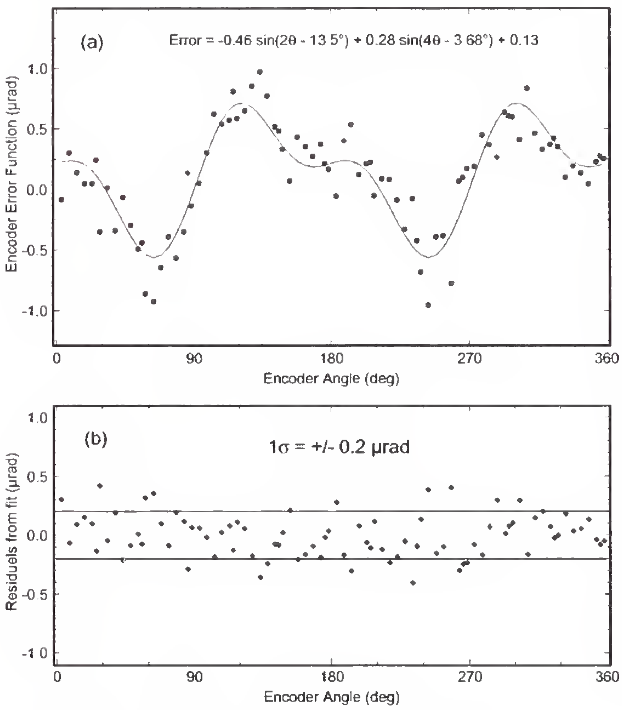


Figure 10. (a) The fitted encoder error function and (b) the residuals (fit minus measurement) for the NIST Vacuum Double Crystal X-Ray Spectrometer encoder.

The magnitude of the error corrections is on the order of 0.5 μrad to 1.0 μrad and the residuals are scattered about zero with a standard error (k=1) of 0.2 μrad (0.00001°). The angle measurement uncertainty contributes $< 1 \times 10^{-6}$ to the relative uncertainty of the wavelength measurements. This improved calibration scheme will be applied to high precision angle encoders used with other x-ray diffractometers in the Division. (L. Hudson)

■**Laser System for Long-range Fabry-Perot Interferometry.** Fabry-Perot interferometry provides the highest resolution of any technique for measuring displacements. The standard practice for measuring a displacement consists of locking a tunable laser to a Fabry-Perot cavity resonance, varying the length of the cavity, and monitoring the optical frequency of the laser. This approach has been useful only for measurements of a rather limited range (≈ 1 micrometer). In order to increase the measurement range of Fabry-Perot interferometry, we have built a computer-controlled scanning laser system that probes two adjacent cavity modes. Displacements up to 50 mm can be measured without sacrificing resolution. The system incorporates independent acousto-optic control of the optical frequencies, and employs frequency modulation spectroscopy to provide error signals in a region in which the laser noise is shot-noise limited. The light output was coupled into a single-mode fiber, enabling remote interrogation of a Fabry-Perot cavity in vacuum. The optical frequencies were measured relative to an iodine-stabilized laser, providing a frequency reference with a fractional accuracy of 2.5×10^{-11}. This system complements the progress we have made in heterodyne interferometry and laser stabilization, and should be of particular interest in future experiments involving thermal expansion of materials and x-ray interferometry.

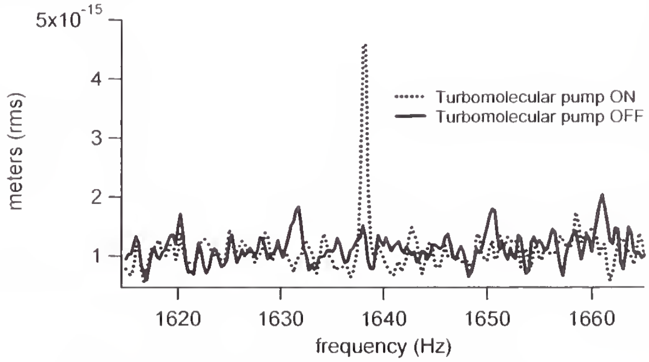
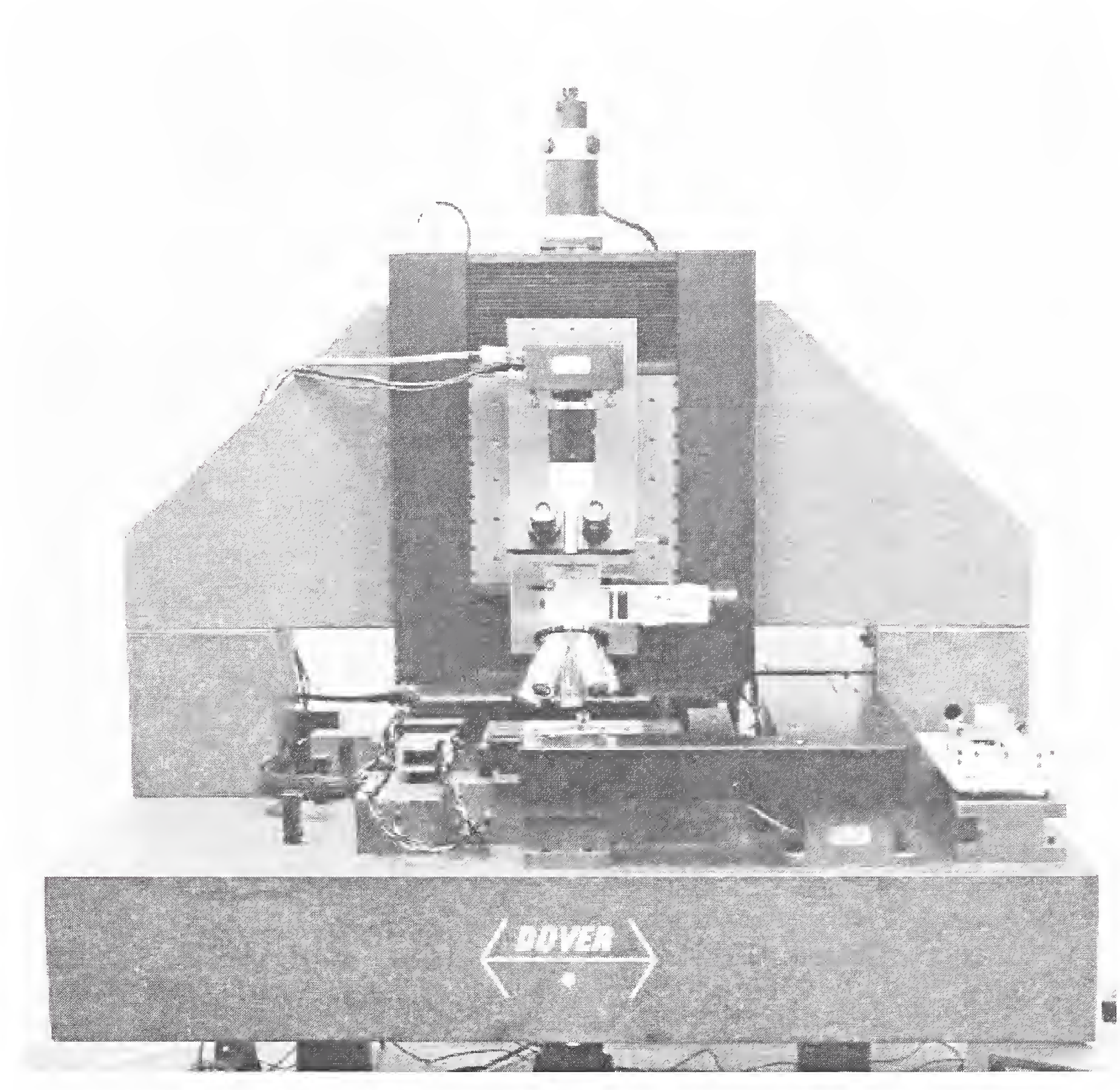


Figure 11. Displacement vs frequency plot for our Fabry-Perot system that illustrates the available high resolution.

The attainable resolution is illustrated in fig. 11, where we studied the vibration contributed to a Fabry-Perot interferometer by a turbomolecular vacuum pump at the second harmonic of its rotation frequency. When the pump was on, a peak appeared whose amplitude corresponds to an rms displacement of less than 5 fm, – a size typical of nuclear radii. (J. Lawall, M. Pedulla, and B. Lantz) □

OPTICAL TECHNOLOGY DIVISION



Overleaf

Aperture Area Measurement Tool: The Optical Technology Division has developed a precision instrument to accurately measure the areas of precision apertures required for the radiometric scales of radiance and irradiance and the photometric scales of luminance and illuminance. The high accuracy of modern radiometry necessitates the use of an interferometrically controlled, coordinate measuring machine to determine absolute aperture areas to better than 0.005 % ($k = 2$).

OPTICAL TECHNOLOGY DIVISION

OVERVIEW

The Optical Technology Division (OTD) supports the NIST Mission by advancing knowledge, developing expertise, providing technical leadership, and delivering the highest quality standards, calibrations, and measurements in targeted areas of optical technology.

The Division has the mandate to provide high quality national measurement standards and support services to advance optical technologies spanning the ultraviolet through the microwave spectral regions in support of customers in industry, government, and academia. The Division also has the institutional responsibility for maintaining two fundamental SI units: the unit for temperature, the kelvin, above 1234.96 K and the unit for luminous intensity, the candela. In carrying out its responsibilities the Division:

- develops, improves, and maintains the national standards for radiometry, radiation thermometry, spectroradiometry, photometry, colorimetry, and spectrophotometry;
- disseminates these standards by providing the highest accuracy measurement services and Standard Reference Materials (SRM's) to customers;
- improves the Nation's technical expertise through publication and training in optical technology;
- conducts research in photophysical and photochemical properties of materials, in radiometric and spectroscopic techniques and instrumentation, and in the application of optical technology; and
- anticipates measurement needs in new application areas of optical technology, such as biophysics, medicine, nanotechnology, and quantum information.

PROGRAM DIRECTIONS

To accomplish these goals in a responsive manner, the Division works closely with other NIST laboratories, industry, academia, and government agencies in developing programs and providing leadership to meet present and future needs in optical metrology.

Pursuant to these objectives, the Division maintains programs in the following areas;

■ **Calibration Services.** The Division provides calibration services and measurements in the areas of radiance temperature, photometry, spectroradiometric sources, spectroradiometric detectors, and optical properties of materials. A quality system is in place for the calibration services that is compliant with ISO Guide 25. The Division maintains a strong commitment to its calibration services, as represented by the nearly completed upgrade of its Facility for Spectroradiometric Calibrations (FASCAL) to FASCAL II.

■ **Standard Reference Materials.** The Division provides and maintains Standard Reference Materials for various optical properties, such as reflectance and transmittance, and for wavelength standards for optical properties measurement instruments.

■ **Training.** The Division offers short courses in photometry and radiation thermometry, with attendees represented by NIST staff, other national metrology institutes, national laboratories, and industry. In the spring, these courses will be complemented by a short course in spectroradiometry, emphasizing remote-sensing applications.

■ **Measurement Comparisons.** The Division participates in a variety of national, international and bilateral comparisons of measurements in areas such as spectral radiance and irradiance, aperture area, and various material properties. These comparisons provide a system of quality control on the national metrology institutes (NMI's) and are an integral component of the recently signed memorandum of understanding between the NMI's.

■ **Cryogenic Radiometry.** The Division has developed various cryogenic radiometers for the high accuracy measurements of optical power by comparison with electrical power. The Division's High-Accuracy Cryogenic Radiometer (HACR) measures optical power to a combined relative standard uncertainty of 0.02 % and is the Nation's standard for optical power. A second generation HACR is presently under development and will have the capability to measure optical power to a combined relative uncertainty of 0.01 %. The Division has also developed other cryogenic radiometers for specialized applications, such as for use in the Low Background Infrared (LBIR) Laboratory. Additionally, standard detectors have been engineered to transfer the high-accuracy radiometric scales to other laboratories.

■ **Spectral Irradiance and Radiance Calibrations with Uniform Sources (SIRCUS).** A laser-based calibration facility has been developed to transfer detector-based spectral irradiance scales, derived from the HACR, to other sensors, including broadband-filtered-detector packages, transfer-standard spectral irradiance detectors, and spectral-radiance measurement instruments. This facility, with a planned wavelength coverage from 200 nm to 20 µm, will be used to realize and improve NIST's illuminance, luminous-intensity, radiance-temperature, color-temperature, and spectral-radiance scales.

■ **Source-Based Radiometry**. The recent upgrade of the Synchrotron Ultraviolet Radiation Facility, SURF II, to SURF III is allowing the Division to expand its capabilities in source-based radiometry. Experiments are being undertaken to rigorously test the ability to calculate the spectral irradiance using Schwinger's equation against absolute measurements of the synchrotron radiation using a cryogenic radiometer. In addition, the Division is implementing a facility at SURF III for source-based spectral irradiance calibrations between 200 nm and 400 nm. The Division's source-based activities at SURF III are complemented by other source-based research in blackbodies and correlated-photons.

■ **Photometry**. 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 base unit for photometry is the candela, a measure of luminous intensity. The Division maintains the candela using a set of well-characterized, filtered detectors, with calibration traceable to the HACR. Photometric scales are distributed to customers through calibrated detectors or by traditional lamps.

■ **Color and Appearance**. In response to industries' need for better color and appearance (gloss, haze, texture, etc.) metrology, the Division is developing new measurement tools and standards to accurately capture visual appearance. As part of this effort, a new colorimeter has just been completed and is presently undergoing testing and validation. Related projects are developing color-measurement standards for self-luminous objects such as LEDs and display devices.

■ **Optical Properties of Materials**. The Division provides measurements of the reflectance, transmittance, and refractive index of materials in the wavelength range from 200 nm to 1000 µm for a range of geometries. These measurements are accomplished using various Fourier-transform and monochromator-based spectrometers. The experimental efforts are complemented by a program in the theoretical modeling of the optical properties of materials and by the development of a facility for the measurement of the emittance of materials at elevated temperatures. An optical properties of materials consortium has been established to provide feedback from industry in this area.

■ **Environmental and Remote Sensing**. The Division works with DoD, NASA, NOAA, EPA, and other U.S. and foreign government agencies in support of a wide range of space-based and terrestrial measurement programs. These programs involve long-term monitoring and survey activity, which require consistent calibration of instruments with diverse deployment platforms. The Division has developed a number of specialized instrumentation, include a traveling version of SIRCUS and various transfer radiometers, and a satellite filter radiometer (NISTAR) to service the remote sensing community.

■ **Thin-Films, Surfaces, and Interfaces**. Various optical techniques are being developed and applied to the investigation of thin-films, surfaces, and interfaces. A novel version of the nonlinear spectroscopic technique of Sum-Frequency Generation (SFG), which allows the measurement of the entire SFG spectrum in the infrared-region of interest on every laser pulse, is being applied to the investigation of semiconductors, biomimetic membranes, and liquid crystal/polymer interfaces. Near-field and confocal optical microscopies are being used to investigate polymer films. Surface topography and properties are studied using a polarized light scattering technique called bidirectional ellipsometry. Specialized polarized-light scattering software has been written to aid the understanding and interpretation of these measurements.

■ **Biophysics.** The Division is developing advanced optical instrumentation and measurement techniques for applications to various areas of biology. A competence effort in THz metrology has lead to the development of laser-based THz spectrometers for spectroscopic, dynamical, and imaging studies. These studies are directed at understanding the large amplitude motions responsible for the flexibility of biological molecules, important, for instance, in protein folding. Complementary spontaneous-Raman investigations and Fourier-transform-infrared hyperspectral imaging studies are also being undertaken. The Division has also been recently awarded competence funding for a project in Single Molecule Measurement and Manipulation. This competence project builds on the Division's expertise in near-field scanning optical microscopy and single-molecule micro-spectroscopy.

■ **Optical Technology for Semiconductor Manufacturing.** The Division has several programs, partially supported by the Office of Microelectronics Programs, which are developing new measurement technologies to aid semiconductor manufacturing. Two of the programs, one dealing with rapid thermal processing (RTP), the other with plasma etching, are directed at improving present semiconductor processing technologies. The RTP effort is developing better process temperature control, while the plasma etching effort is developing better process chemistry control. Other programs are providing critical measurements of optical properties necessary for future 157 nm lithographic equipment. Very accurate indices of diffraction are being measured for candidate materials for the optical components of the next generation of lithography tools, while deep UV detector responsivities and damage thresholds are being quantified to aid the development of accurate irradiance probes for determining 157 nm dose levels in lithographic applications.

In addition to these activities, the Division staff participate in the activities of the Council for Optical Radiation Measurements (CORM), the International Commission on Illumination (CIE), the Optical Society of America (OSA), the International Society for Optical Engineering (SPIE), and other professional societies. The staff provides expertise and leadership in documentary standards activities through the American Society for the Testing of Materials (ASTM) and other standards organizations. These various activities allow the Division to stay abreast of present and future needs of American industry for optical technology measurements and standards. To effectively respond to these needs, the Division has developed a strategic plan that contains a clear set of objectives that are reviewed and updated on a yearly basis and furnish the outline for the individual performance plans of each staff member.

MAJOR TECHNICAL HIGHLIGHTS

■ **Validated Heat-Flux Sensor Responsivities Using a Spherical Blackbody.** The Division has been researching new methods to accurately determine the radiative responsivities of heat-flux sensors, widely used in fire and aerodynamic tests of aerospace vehicles and components.

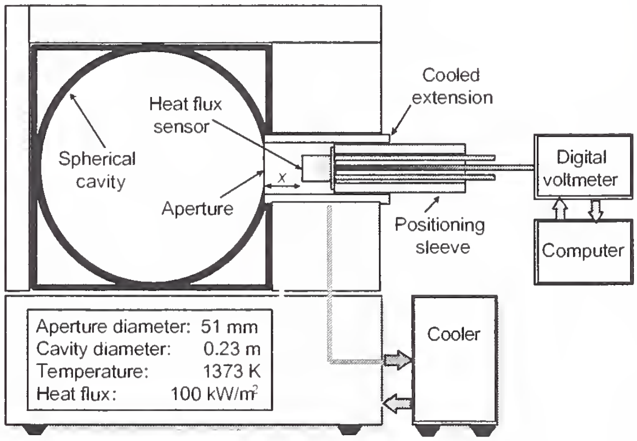


Figure 1. Spherical blackbody furnace used for the radiative calibration of heat-flux sensor responsivities to an expanded uncertainty of 2 % ($k = 2$).

Comparison of radiative heat-flux measurements between various laboratories using a variety of different techniques reveal that presently claimed responsivities vary by as much as 15 %. Studies at NIST indicate, however, that the sensor responsivities are stable and reproducible to better than 1 % over a period of several years. The calibration method developed by the Division uses an electrical substitution radiometer to determine the absolute heat flux at the sensor from a cylindrical heat-pipe blackbody (detector-based method) and has an expanded uncertainty of 2 % ($k = 2$). To validate this detector-based method, the Division has developed a totally independent source-based calibration procedure in which a sensor is plunged into a 0.23 m diameter high-temperature spherical blackbody, as shown in fig. 1, and the heat flux is directly calculated using the Stefan-Boltzmann equation. This approach also yields a responsivity with an expanded uncertainty of 2 % ($k = 2$). Sensors calibrated using the two approaches give responsivities that agree to within 2 % ($k = 2$), validating the two methods. The availability of accurate heat-flux sensor calibrations from NIST allows sensor users and manufacturers to better assess the performance of their calibration methods and offers validated calibration procedures for implementation by other laboratories. (B. Tsai, D. DeWitt, and M. Annageri)

■ **A New Millimeter-to-THz Spectroscopy Tool for Plasma-Etching Chemical Diagnostics.** With support from ATP Intramural funding and building on expertise developed through a Competence program in Advanced Terahertz (THz) Metrology, the Optical Technology and Atomic Physics Divisions have collaborated on the development of a new spectroscopic technique for the characterization of the complex chemistry that occurs in a semiconductor plasma-etching reactor. The understanding and the control of this chemistry is critical to the microelectronics industry as it moves toward more complex multistep etching processes, larger wafers, and smaller and higher-aspect-ratio features. The new technique uses millimeter-to-THz linear-absorption spectroscopy with backward-wave oscillator (BWO) coherent radiation sources to determine the density and temperature of plasma species, such as radicals, ions, and molecules, along the radiation propagation path.

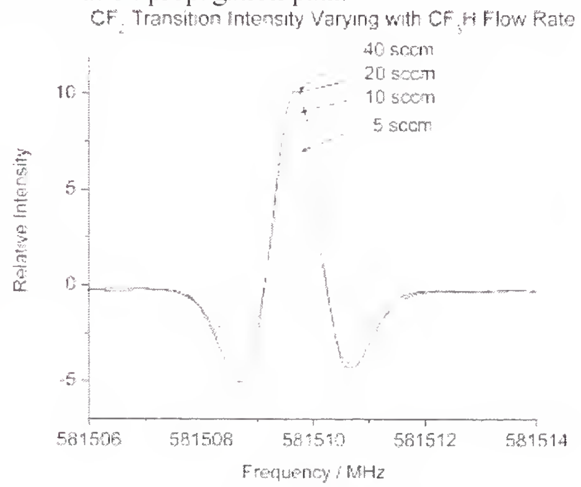


Figure 2: Second-derivative submillimeter spectra of an absorption line of CF_2 in a 250 W inductively coupled CF_3H plasma in a Gaseous Electronics Conference (GEC) reference cell at a constant cell pressure of 1.3 Pa and various flow rates of CF_3H. The spectra demonstrate that the production of CF_2 is increased at high flow rates.

The technique is a significant improvement over previous methods as it provides simple and unambiguous molecular identification and quantification of a broad range of molecular species. Initial tests (see fig. 2) using a standard test reactor demonstrated the detection of CF_3H, CF_2, CF, CO, and CF_2O in a low-pressure, inductively coupled, CF_3H plasma, as might be used, for instance, in the etching of SiO_2 on Si wafers. Decomposition of the CF_3H in the plasma is found to be nearly complete at 90 %. The production of CO and CF_2O is attributed to etching of a quartz (SiO_2) dielectric shielding plate by the CF_3H decomposition products or to reactions of these products with water-vapor impurities in the reactor feed gas. The latter possibility is presently being addressed by directly examining submillimeter absorption lines of water vapor in the reactor. Independent translational, rotational, and vibrational temperature measurements are also possible with the technique, furnishing additional valuable input data to plasma models. Efforts are being made to extend the measurement frequency to above 1 THz using solid-state photomixers to allow the direct measurements of the HF concentration, an important component of hydrogen-rich, hydrofluorocarbon-based, etching plasmas. (E. Benck, G. Golubiatnikov, D. Plusquellic, and G. Fraser)

■ **Radiometric Calibration of the NIST Advanced Radiometer (NISTAR) and Earth Polychromatic Imaging Camera (EPIC) for the TRIANA Satellite.** OTD has completed the radiometric calibration of two instruments, NISTAR (NIST Advanced Radiometer) and EPIC (Earth Polychromatic Imaging Camera), both planned for deployment on the Triana satellite. The Triana satellite, after launch by the Space Shuttle, is to be positioned in an orbit at the Lagrange-1 point to allow continuous monitoring of the sunlit Earth. NISTAR will measure the absolute irradiance of the Earth while EPIC will provide hourly, spatially resolved measurements of cloud properties, ozone concentration, and aerosol levels of the Earth's atmosphere.

NISTAR, originally designed by NIST, was calibrated at NIST using the capabilities of the Division's Spectral Irradiance and Radiance Calibrations with Uniform Sources (SIRCUS) facility. During the tests, NISTAR was illuminated to mimic its view of the Earth from space. The resulting relative uncertainties on the calibration are below 1 %. The NISTAR instrument has since been delivered to

NASA's Goddard Space Flight Center and integrated onto the Triana satellite.

The bulk of the EPIC radiometric calibration was performed during thermal and vacuum testing of the instrument at Lockheed Martin in Palo Alto, California in December 2000, with additional, final measurements performed in October 2001 at the Goddard Space Flight Center. The intense, multi-day calibration effort required the unique radiometric expertise of NIST staff, specialized calibration sources and detectors, on-site evaluation of results, and modifications to the initial calibration plan when circumstances or scheduling changed. Preliminary results have already been made available to the mission science team. (T. Early, D. Allen, C. Johnson, J. Rice, S. Lorentz, S. Brown, and K. Lykke)

■ **THz Spectra of Biomolecules.** As part of a Competence program in Advanced Terahertz Metrology, the Division has developed a novel THz spectrometer for the investigation of large-amplitude vibrational motions in biomolecules, important for their flexibility. The capabilities of the instrument have been demonstrated by recording THz spectra of two small biological molecules, biotin and riboflavin, and the protein myoglobin.

THz radiation is produced by difference frequency mixing of two near-infrared laser beams, separated in frequency from 0.1 THz to 4 THz, in a solid-state GaAs photomixer. The THz radiation is directed through the sample and detected by a liquid-He-cooled bolometer. To increase sensitivity and reduce spectral artifact absorptions, the intense atmospheric water-vapor absorption present at THz frequencies and the etalon or standing-wave structure characteristic of this spectral region, were effectively eliminated by placing the photomixer, liquid-He-cooled sample, and bolometer in a common vacuum system, with no windows separating the components.

Spectra were recorded with the samples cooled to 4.2 K to reduce inhomogeneous broadening for increased spectral resolution. The spectra of biotin and riboflavin reveal a number of low-frequency vibrations at frequencies less than 4 THz with linewidths of approximately 0.03 THz. Complementary measurements using Raman spectroscopy have also been performed, providing additional information on the low frequency vibrations. Efforts are presently underway to identify these motions with specific nuclear displacements.

In contrast to biotin and riboflavin, the THz spectra of myoglobin is broad and structureless Additionally, the transmission significantly increases with temperature. Previous studies of proteins in this spectral region revealed significant spectral structure, attributed to standing-wave patterns, which are effectively removed in our study. Our myoglobin observations challenge the basis for the application of THz spectroscopy to biological warfare agent detection, that is, that biological agents will have structured THz spectra that will aid their detection and identification. (T. Korter, D. Plusquellic, A. Hight Walker, E. Heilweil, and G. Fraser)

■ **Radiometric Calibration of the Marine Optical Buoy (MOBY).** The Division is providing radiometric calibration of the Marine Optical Buoy (MOBY) to ensure the accuracy of the measured down-welling irradiances and ocean-leaving radiances used to calibrate or validate ocean-color measurement satellite instruments, such as the Sea-Viewing Wide Field-of-View Sensor (SeaWifs) and the Moderate Resolution Imaging Spectroradiometer (MODIS). The Division is supporting the radiometric calibration of MOBY by both traveling to the deployment site in Hawaii to perform calibrations of the buoy and by developing standards and methodologies to directly calibrate and test a duplicate MOBY spectrograph at NIST. This spectrograph, denoted MOS for Marine Optical System, was characterized at NIST using SIRCUS, in response to concerns about stray or scattered light causing significant errors in the instrument readings, particularly at shorter wavelengths (see fig. 3). The success of the SIRCUS measurements led to the development of a "Traveling" SIRCUS to allow direct calibration of the MOBY instrument in Hawaii using the Division's laser-based monochromatic radiance sources. The improved calibration of MOBY is allowing the correction of the legacy ocean radiance and irradiance data, which is being made available to researchers dependent on these measurements. The project has also demonstrated the unique advantages of using SIRCUS for the calibration of remote sensing instruments. (C. Johnson, S. Brown, and K. Lykke)

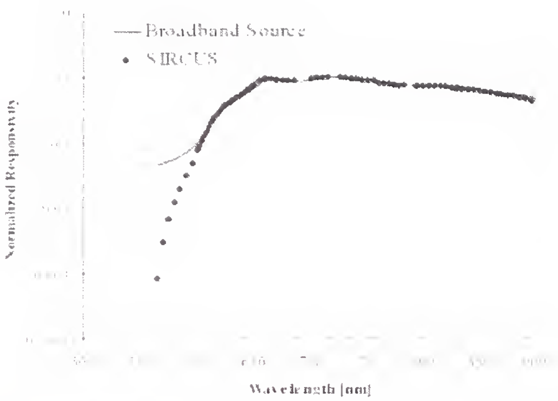


Figure 3. This plot is the normalized instrument responsivity versus wavelength for the Marine Optical Spectrograph (MOS) as measured using a broadband radiation source and a monochromatic source furnished by the laser-based SIRCUS calibration facility.

■ **Traveling SIRCUS.** The Division is actively involved in providing radiometric calibration for remote sensing satellites. It is often desirable to be able to perform the calibrations at the customer's site, typically an aerospace company or a NASA or DoD facility, either because of the instruments large size or fragility, scheduling constraints, or special clean-room or environmental limitations. To be able to provide the highest accuracy spectroradiometric calibrations requires that we bring the capabilities of SIRCUS, i.e., broadly tunable single-frequency radiance and irradiance standards, to these sites. We are presently developing such capabilities in the visible and near infrared, which we are calling Traveling SIRCUS. Upon completion, Traveling SIRCUS will consist of Ti:Sapphire and dye lasers pumped by a solid-state diode-pumped laser, a small Ar-ion laser, a solid-state frequency doubler, and integrating spheres, providing a monochromatic source of continuous spectral radiance from the ultraviolet to the near-infrared, that is, from 350 nm to 980 nm. While at NIST, the system is used as a research tool to advance the capabilities of SIRCUS, as the present SIRCUS instruments are frequently unavailable due to the calibration workload. The initial deployment of Traveling SIRCUS was made recently at the MOBY site in Hawaii (see above). (C. Johnson, and S. Brown, K. Lykke)

■ **Calibration of Light-Pipe Radiation Thermometers for Applications in Rapid Thermal Processing (RTP).** To help improve temperature measurements in semiconductor RTP, the Division has undertaken extensive research on light-pipe radiation thermometers (LPRT's) and their calibration. The goal of the RTP program is to enable the semiconductor industry to achieve temperature measurements of better than 2 °C at 1000 °C, a goal stated in the Semiconductor Industry Association roadmap. Improved LPRT measurements are essential to achieving this goal, as they are the predominant temperature measurement instruments in RTP. The Division's research has led to a calibration protocol and a set of recommendations to ensure accurate temperature measurements with LPRT's.

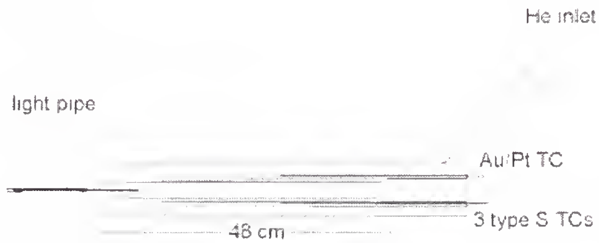


Figure 4. This figure shows the calibration of a light-pipe radiation thermometer (LPRT) using a sodium heat-pipe blackbody for temperatures between 700 °C and 950 °C. TC refers to thermocouple.

Expanded uncertainties of 0.6 °C (k = 2) were achieved for the calibration of LPRT's for radiance temperature near 1000 °C. The radiance temperature standard was a well-characterized, high-emissivity, sodium-heat-pipe blackbody, as shown in fig. 4. To be useful in applications, LPRT's must retain their calibration over a long period of time to limit the down time of the RTP chamber. Short-term, 10 min variations in the sensor response were found to be less than 0.1 °C, while long-term, 1 yr variations in the sensor response were less than 1 °C. These measurements indicate that LPRT's are capable of making temperature measurements to within 1 °C. (C. Gibson, F. Lovas, and B. Tsai,)

■ **Intrinsic Birefringence in CaF_2.** Deep ultraviolet photolithography technology has turned to crystalline CaF_2 for the next generation of refractive optical elements because of the poor transmission of glasses at 193 nm and 157 nm. Despite the cubic symmetry of CaF_2, its crystalline nature introduces spatial-dispersion-induced birefringence, which results from the finite wave vector of the light. Measurements made in this Division and the Atomic Physics Division were supported with theoretical calculations performed in collaboration with the Electron and Optical Physics Division. We have successfully modeled it in CaF_2, BaF_2, and several semiconductor materials from first principles, obtaining good agreement with all measurements.

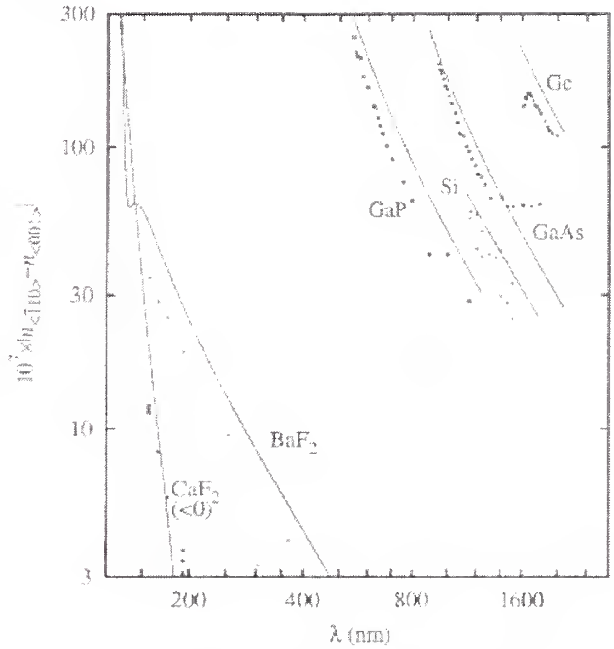


Figure 5. Index difference for two polarizations for light propagation along the [110] direction.

Our main results are presented in fig. 5. Our key findings are as follows. First, the birefringence in CaF_2 is about ten times larger than specifications desired by the semiconductor industry. Second, the birefringence in CaF_2 is opposite in sign from that in BaF_2 and many other materials. Third, a mixed $Ca_xBa_{1-x}F_2$ crystal may exhibit zero birefringence at chosen wavelengths by tuning x. (E.L. Shirley)

■ **High-level UV Irradiance Calibration.** We have calibrated the irradiance responsivity of a diode array spectrophotometer designed to measure the irradiance at the exit port of an advanced xenon-lamp-illuminated integrating sphere source (BFRL). The 2 m diameter-integrating sphere was designed for accelerated UV aging studies of advanced materials over the spectral range from 290 nm to 400 nm, with irradiance levels at the sphere exit port calculated to be as high as the equivalent irradiance from 30 suns. A fiber-coupled diode array spectrophotometer, equipped with an integrating sphere fore optic, is used to calculate the irradiance at an exit port.

We used a collimated laser source to determine the spectral power responsivity of the spectrophotometer as several wavelengths over the 300 nm to 400 nm spectral region. We then determined the effective aperture area of the input fore optic, and averaged the response over the entrance aperture, to establish the irradiance responsivity. To obtain an estimate of the responsivity over the entire spectral range from 300 nm to 400 nm, we measured the output of a Xe arc lamp using a reference standard filter radiometer, and interpolated the radiance between filter radiometer tie points. This relative measurement was subsequently scaled at 334 nm to obtain a measure of the absolute spectral responsivity of the spectrophotometer. (S. Brown and E. Bryd, with J. Chin, Div. 862)

■ **Improved Low Background Infrared Facility (LBIR) Broadband Blackbody Calibrations.** The LBIR broadband blackbody calibrations can now be performed at 1 nW power levels with 1 % Type A (random contributions) uncertainty. This achievement is a direct consequence of improvements in background environment stability and the use of the new LBIR Absolute Cryogenic Radiometer (ACRii), and corresponds to a factor of 10 improvement in power measurement capability. A new refrigerator system with greater cooling capacity and better temperature stability is partially responsible for the improved background environment. The calibrations are also now being performed in the newer Spectral Calibration Chamber (SCC) with its more efficient cryoshrouds. These improvements have changed the background environment from 25 K with a relatively common 0.1 K drift in temperature in a 10 minute period, to a 17 K environment with drifts in temperature of less that 0.01 K over a 10 minute period. The electronics-limited 10 pW sensitivity of the ACRii can be fully used in the new stable environment. This can be compared to the use of the older ACR in the Broadband Calibration Chamber (BCC) where the noise floor was 100 pW at best. Figure 6 shows an example of a 97 pW power measurement using the ACRii in the SCC with the new refrigerator. These improvements have made it possible to meet most of the recent calibration requirements for the blackbody sources from the aerospace contractors of the Ballistic Missile Defense Organization (BMDO). (A. Carter and S. Lorentz)

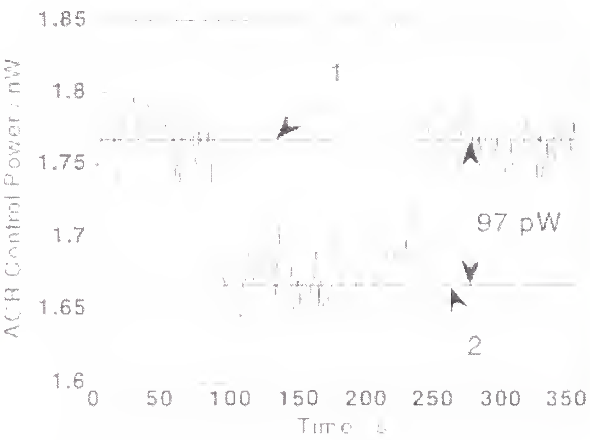


Figure 6. The plot shows 97 pW power measurements made using the LBIR's new Absolute Cryogenic Radiometer (ACRii) in the new Spectral Calibration Chamber. (1) ACRii heater power without incident optical radiation. (2) ACRii heater power with incident optical radiation.

■ **NIST-NPL CCPR Intercomparison of Mid-infrared Transmittance and Reflectance Scales Shows Good Agreement.** For the first time, an international intercomparison of infrared spectrophotometry scales at the National Measurement Institute (NMI) level has been performed. NIST and the National Physical Laboratory (NPL) of the UK have undertaken a comparison of scales for regular transmittance and reflectance in the mid-infrared part of the spectrum. The comparisons have been carried out as "Supplementary Comparisons" of the Consultative Committee for Photometry and Radiometry (CCPR) of the Bureau International des Poids et Mesures (BIPM). The transmittance comparison was performed using a Schott NG11 glass as the comparison artifact. Measurements were carried out at seven wavelengths between 2.5 μm and 5 μm where the gradient of the transmittance profile was flat. The reflectance comparison was performed using three different artifacts – a non-overcoated front-aluminized glass mirror, a NiCr coating on a glass substrate, and an uncoated plate of Schott BK7 optical glass – to cover a range of reflectance values. Measurements were carried out for near-normal incidence between 2.5 μm and 18 μm.

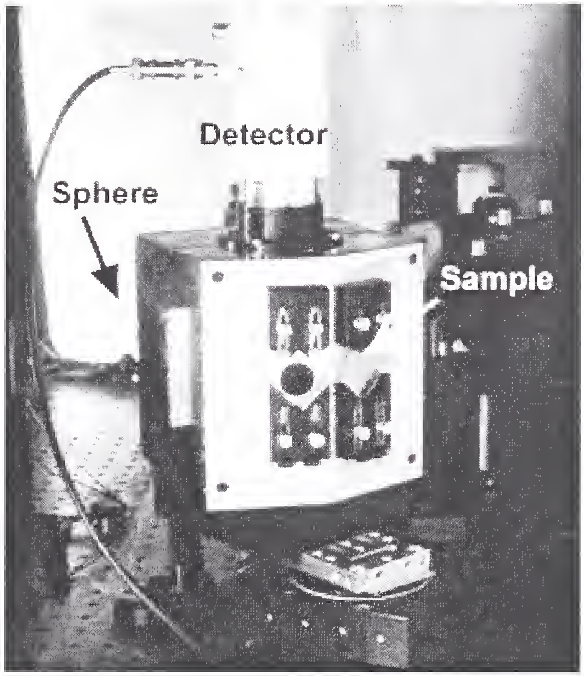


Figure 7. Photograph of the NIST integrating sphere for absolute infrared spectral transmittance and reflectance.

The diffuse gold integrating sphere used to perform the NIST measurements is shown in fig. 7. In all cases there was agreement between the two national labs, within the combined expanded uncertainties. (L. Hanssen and S. Kaplan)

■ **Development of Monte-Carlo Integrating Sphere Reflectometer Model.** The Division has developed a highly efficient code based on Monte Carlo methods and ray-tracing to study the performance of an integrating sphere designed for hemispherical-directional reflectance measurement. This code has been used to perform a comparative analysis of different sphere designs, with variation of critical sphere parameters including sphere wall reflectance and sample scattering characteristics. Integrating spheres have been used for nearly a century for reflectance measurements. However, due to the inherent difficulties of accurate uniform collection of all reflected or transmitted light from a diffuse sample, significant measurement errors and uncertainties are common. A significant contributor is the complexity of analytical approaches to sphere analysis that ultimately necessitates the use of approximations. Numerical modeling approaches do not require approximations, but the long computation times even with the fastest computer processors, limit the accuracy of the results.

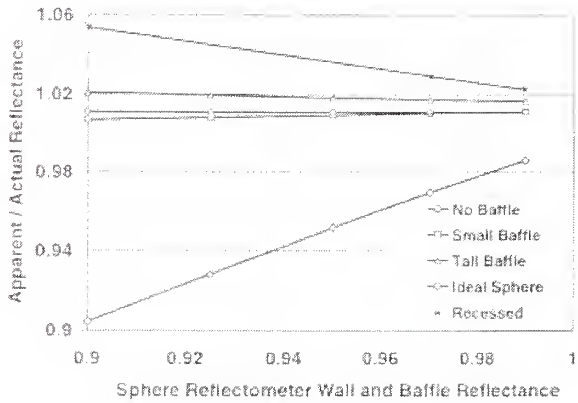


Figure 8. This plot demonstrates the effect of different design options, for integrating spheres, on the accuracy of reflectance measurements.

Our code incorporates a number of significant time-saving features, that enable us to reduce statistical uncertainties to less than 0.1%, even for very low efficiency spheres. Numerical modeling methods offer the most promise for sphere analysis, design, and error reduction. For example, the effect of different design options including baffling arrangements on the measurement accuracy of the sphere was analyzed with results shown in fig. 8. The studies have resulted in a specific sphere design to be built for near-infrared reflectance and non-contact temperature measurements. (L. Hanssen)

■ **LED Sphere.** Currently, typical light sources used for radiometric, photometric, and colorimetric calibrations use broad-band, incandescent or Xenon-arc lamps. Most of the radiation from these sources lies in the infrared spectral region, and is consequently not useful for photometric and colorimetric calibrations. Colorimeters and photometers often measure sources (such as displays) with significantly different spectral distributions from the calibration source. The errors in these measurements are often unknown, and can be quite large. For example, colorimeters can be calibrated against an incandescent source with minimal errors of 0.001 or less in x,y chromaticity. However, errors in measurements of displays using these colorimeters can be larger than 0.01 in x,y. Development of a stable, spectrally tunable, radiometric source could positively impact a variety of photometric, colorimetric, and radiometric programs. Recent advances in LED materials and their manufacturing processes have resulted in the commercial availability of LED's with colors spanning the entire visible spectrum. We are exploiting this newly enhanced technology in the design of a tunable spectral distribution integrating sphere source (ISS).

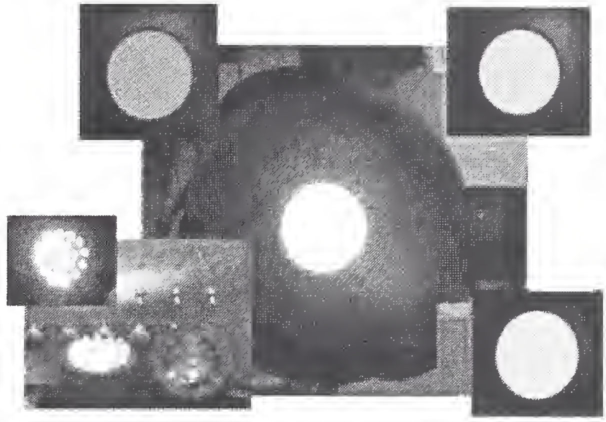


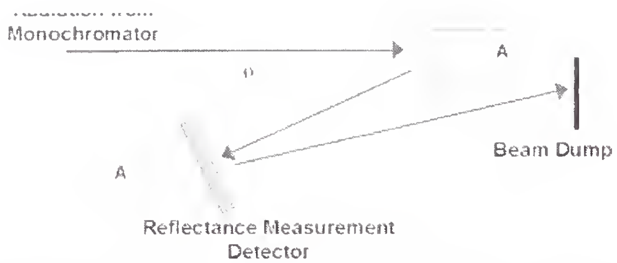
Figure 9. Picture of LED sphere showing red (upper left), green (upper right), blue (lower right), and white (center) outputs.

We have developed a prototype tunable LED-based ISS, shown in fig. 9. The integrating sphere is equipped with 10 different LED's with spectral distributions ranging from the blue to the red. By varying the drive current of the individual LED's, the sphere spectral radiance can be tuned over a broad wavelength range enabling calibrations of colorimeters and spectroradiometers against the ISS with different spectral distributions. (S. Brown and G. Eppeldauer)

■ **Detector Damage/Depth Dependence.** A new detector measurement capability, illustrated in fig. 10 has been added to the UV radiometric beamline at the Synchrotron Ultraviolet Radiation Facility (SURF III). The beamline is capable of calibrating photodetectors from 130 nm to 600 nm.

Figure 10. Schematic of the NIST quantum efficiency measurement setup.

The new setup allows simultaneous measurement of the spectral reflectivity and the spectral power responsivity of the detector. With the measurement of both quantities, the important detector quantity of internal quantum efficiency, the response of the detector per total amount of the radiation absorbed by the detector, can be deduced. The internal quantum efficiency of a detector depends only on the internal mechanism of converting photons to electrons and the collection of electrons because the variation in radiation loss due to detector surface reflectivity is eliminated during the calculation of internal quantum efficiency. In the visible, the



internal quantum efficiency of a working standard silicon photodiode is close to 100 % and was modeled to provide a detector calibration curve by extrapolating to all wavelengths from visible to near infrared. The new setup measures both reflectivity and power responsivity simultaneously to reduce the uncertainty in deriving the internal quantum efficiency caused by effects like positioning of the detector and contamination of the detector surface when measurements are performed separately. We have studied the internal quantum efficiency of a variety of photodetectors, especially UV detectors with potential application for the photolithographic industry. Our measurements of the internal quantum efficiency have provided us with insight into the photon detection mechanism. We were able to model the detector internal quantum efficiency and found clear evidence of interface trap states inside some of the detectors. We also found evidence that these trap states were formed when a detector is damaged by UV radiation. The capability of studying detector internal quantum efficiency has become an important tool for detector characterization. (R. Gupta and P. Shaw)

■ **Mutual Recognition Arrangement.** A Mutual Recognition Arrangement (MRA) was drawn up by the International Committee of Weights and Measures (CIPM), under the auspices of the Meter Convention. At a meeting held in Paris on October 14, 1999, the directors of the national metrology institutes (NMIs) of 38 Member States of the Meter Convention and representatives of two international organizations signed the MRA.

This Mutual Recognition Arrangement is a response to a growing need for an open, transparent, and comprehensive scheme to give users reliable quantitative information on the comparability of national metrology services and to provide the technical basis for wider agreements related to international trade, commerce, and regulatory affairs. The eventual outcome of the MRA will be statements of the measurement capabilities of each NMI in a web-accessible database, known as the key comparison and calibration database (KCDB), maintained by the BIPM.

The OTD has been involved in a number of international intercomparisons including spectral responsivity (from 200 nm to 1600 nm), spectral irradiance, aperture area, luminous intensity and luminous flux, spectral regular transmittance, and diffuse spectral reflectance. These intercomparisons form the underpinning of the MRA verification process and are listed in Appendix C of the MRA.

The acceptance of NIST's capabilities for Thermometry and Photometry and Radiometry are anticipated for spring of 2002. Additional information on the MRA and the KCDB can be found at http://kcdb.bipm.org/BIPM-KCDB/ (C. Gibson, T. Early, Y. Ohno, and S. Bruce)

■ **Determining the Molecular Basis of Adhesion at Buried Interfaces.** Adhesion between dissimilar materials is of critical importance to a variety of industrial products and processes, e.g., coatings, fiber-reinforced composites, multilayer electronic devices, and integrated circuit packaging. Until recently, a technique to adequately characterize buried interfaces, and in particular, to determine the molecular structure at such an interface has been lacking. We have been developing novel state-of-the-art non-linear optical spectroscopies, such as Sum Frequency Generation (SFG), to explore molecular structure at material surfaces and buried interfaces for a variety of applications.

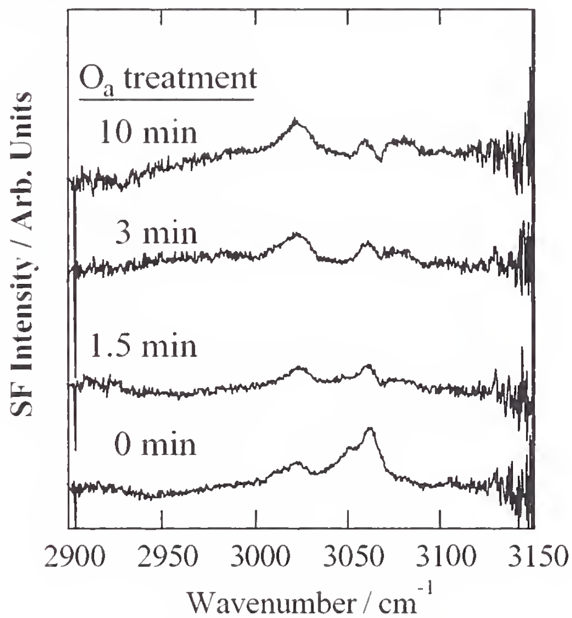


Figure 11. Vibrationally resonant SFG spectra illustrating changes in molecular orientation which correlate with atomic oxygen treatment of the substrate.

We have extended our previous studies of free polymer surfaces [J. Phys. Chem. **B** 105, 2785 (2001)] to investigate the molecular structure of buried polymer interfaces, specifically, the polystyrene(PS)/spin-on-glass(SOG) interface. Thin films of PS and SOG of specific thicknesses are used to create optical interferences that modulate the signal coming from the interface of interest. The SOG substrate is comprised of a hydrogen silsesquioxane inorganic polymer film, which, when properly cured, has optical and chemical properties similar to glass. However, the untreated surface of a SOG thin film is terminated by silicon-hydrogen (Si-H) bonds, resulting in a low free energy, hydrophobic surface. Increasing exposures of this native SOG surface to UV activated oxygen species decreases the number of Si-H bonds in favor of silicon-hydroxyl (Si-OH) bonds, which form a high free energy, hydrophilic surface. Figure 11 shows the vibrationally resonant SFG spectra of the PS/SOG interface for a series of PS/SOG samples with varying exposure of the SOG substrate to activated oxygen (O_a). Analysis of the SFG spectrum for the native SOG substrate (i.e., 0 min O_a treatment), gives an absolute orientation of phenyl groups pointing away from the PS film (i.e., towards the SOG substrate) with an absolute molecular orientation similar to that observed previously for phenyl groups at the free PS surface. Changes in the SFG spectra for the O_a treated SOG substrates correlate with orientational changes in the tilt and twist angles of the pendant phenyl groups. The observed spectral changes suggest the phenyl groups alter their orientation to enable more favorable chemical interactions with surface Si-OH species.

The changes in molecular orientation observed with SFG have been correlated with the adhesive strength of the polystyrene thin-film/glass interface. PS films peel off the untreated, low surface energy, hydrophobic SOG substrates; whereas PS films adhere to the higher surface energy, hydrophilic SOG substrates. This work paves the way for critically addressing the issues of molecular based adhesion between dissimilar materials in a variety of disciplines. (K. Briggman, J. Stephenson, with P. Wilson and L. Richter, Div. 837)

■ **Scattering by Small Metallic Spheres**. Small (50 nm to 200 nm) polystyrene latex (PSL) spheres are used by the semiconductor industry to calibrate the particle-sizing function of light-scattering-based scanning surface inspection instruments. However, these spheres are not typical of real-world particles encountered on production lines. The industry needs accurate models for scattering by real-world particles to design instruments and to provide the basis for particle size and particle identification using the instrument.

In 1986, Bobbert and Vlieger described the solution to the scattering of light by a sphere on a flat substrate. However, it was found that for metallic particles on a highly reflecting silicon substrate, numerical instabilities caused their implementation to fail long before convergence was achieved. Painstaking efforts were made to find the roots of the instabilities, resulting in a final implementation of the theory, which is efficient, robust, and accurate. This solution was extended to account for uniform coatings on the substrate and the sphere.

In collaboration with NIST's Building and Fire Research Laboratory and the University of Maryland, methods were developed in the Division to generate size-monodisperse copper spheres and to deposit them onto silicon wafers. Polarized light scattering measurements, performed at a wavelength close to the copper plasma frequency, were performed on these samples. The results yielded excellent agreement with the theoretical calculations (see fig. 12). The implementation of the theory, made publicly available through NIST's SCATMECH library of scattering codes, can act as a benchmark by which approximate codes, suitable for more complex particles, can be compared. (T. Germer)

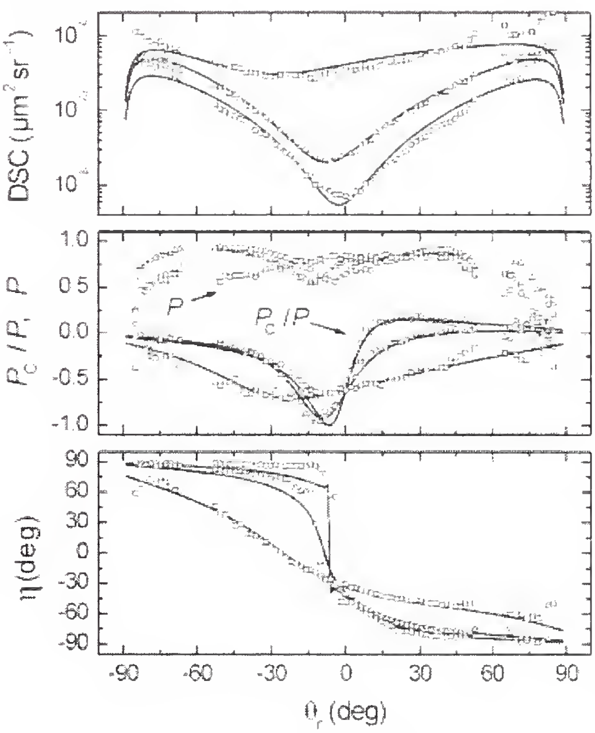


Figure 12. Light scattering parameters are plotted [differential scattering cross-section (DSC), the degree of polarization (P), the normalized degree of circular polarization

(P_C/P), and the principal angle of the polarization ( )] for 96 nm (circles), 113 nm (triangles), and 158 nm (squares) copper spheres on silicon wafers measured in the plane of incidence using 45° polarized, 633 nm light incident at an angle of 60°. The solid curves represent the predictions of the Bobbert-Vlieger theory.

■ **Measuring the Dynamics of Individual RNA Molecules.** We have measured the rotational dynamics of single RNA molecules tethered to a glass substrate. Recent single molecule experiments and many gene-chip technologies rely on the ability to tether a molecule to a surface without changing its activity. An assumption is often made that the molecules are unaffected by the presence of the surface. Here we explore this assumption on a single-molecule basis. A common scheme for tethering nucleic acids to surfaces exploits the high affinity bond of biotin with streptavidin (fig. 13). Here we label a single stranded RNA molecule on its 3' end with a dye called Cy3™. At the 5' end, a single biotin molecule is attached to the RNA via a flexible tether. Streptavidin links the biotinylated RNA molecule to a coverslip coated with biotinylated bovine serum albumin (BSA). (L. Goldner, K. Weston, W. Heinz, and A. Bardo)

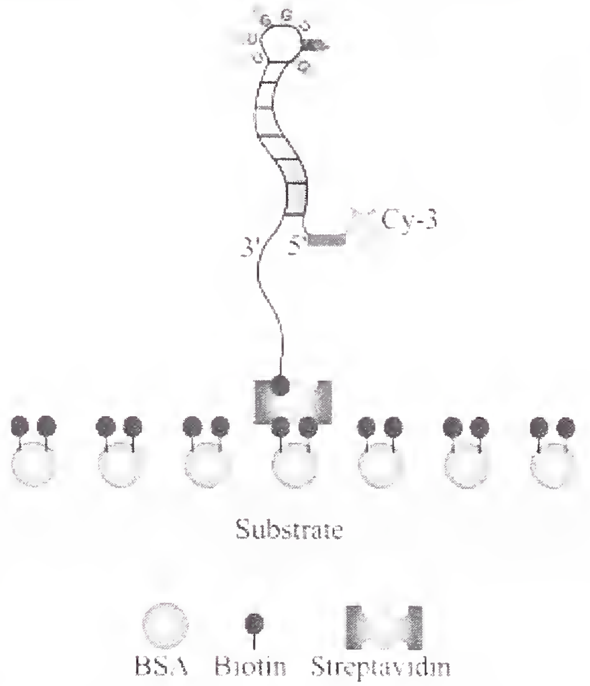


Figure 13. Tethering RNA to a surface.

■ **Infrared Imaging of Combinatorial Solar Cell Silicon-Hydride Films.** Determining the chemical and nano-structural properties of modified silicon surfaces is of great importance to improve solar cell efficiency and use for future US and global solar energy conversion needs. To this end, Division researchers obtained the first infrared spectral images of a 16-element combinatorial array of 1 μm thick amorphous and polycrystalline deposited films on a silicon substrate. Using a 256×256 InSb infrared array detector coupled to a step-scan FTIR interferometer, infrared absorption images, as shown in fig. 14, identified Si-H film densities critical to solar cell applications. This investigation provided key structural information for samples obtained from the National Renewable Energy Lab by using OTD's unique infrared imaging capabilities.

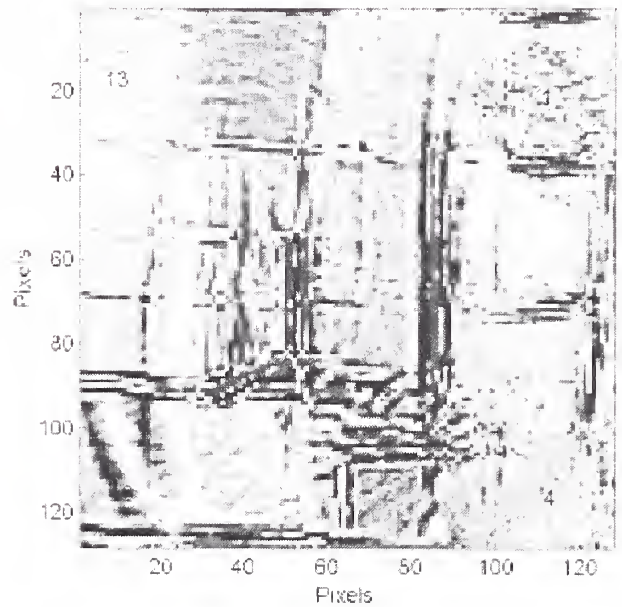


Figure 14. Infrared absorption at 2000 cm^{-1} for Si-H surface species in a 4×4 CVD film array (dark gray → white denotes increasing Si-H density and infrared absorption).

Chemical vapor deposition of silicon-hydride films in the presence of controlled hydrogen overpressures and substrate temperatures affects the amorphous and crystalline properties of the deposited film. These films also show enhanced hole mobilities with improved photon to carrier conversion efficiency and long-term stability compared to conventional amorphous silicon materials. Using NIST's infrared imaging capabilities on the 4×4 array demonstrated that this technology rapidly identifies Si-H film concentrations and provides correlations with independently measured film structure and conversion efficiencies. The technique also provides quick visual assessment of the uniformity of grown films. It is envisioned that future related studies of compositional or substrate temperature gradient deposited films could lead to the discovery of optimal growth conditions for improved solar cell devices. (T. Heimer and E. Heilweil)

■ **Carrier Lifetimes of Low-Temperature GaAs Measured for Terahertz Antenna Applications.** To better understand the broadest attainable frequency bandwidths of terahertz (THz) generators and detectors, Division researchers teamed with NIST's EEEL to measure carrier lifetimes in low-temperature GaAs films (LT-GaAs). Improving and controlling growth conditions for LT-GaAs films is critical for obtaining optimum performance in high-frequency THz devices. Charge mobility in antenna semiconductor substrates directly affects the output pulse duration and speed, thus producing varying terahertz frequency bandwidths in spectroscopic or imaging applications.

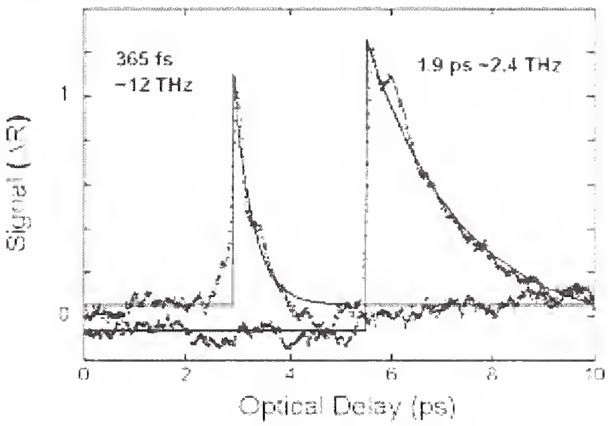


Figure 15. Transient reflectivity recovery dynamics for two samples of 1 μm thick MBE-grown LT-GaAs on GaAs substrates. The 365 fs carrier decay time is for EEEL material: while the slower 1.9 ps decay time is for a commercial sample.

LT-GaAs films are known to yield several picosecond carrier lifetimes compared to GaAs or related semiconductors (100's of ps). High electron and hole mobilities correlate with shorter lifetimes - achieving short carrier lifetime films is preferred. Lifetimes for 1 μm thick chemical vapor deposited LT-GaAs films were measured using an amplified femtosecond Ti:Sapphire system with 50 femtosecond, 800 nm pulses. A reflection pump-probe apparatus directly monitored the time-dependent carrier reflectivity change after pump excitation. Figure 15 shows transient reflectivity results for films produced under ostensibly similar pressure and temperature growth conditions by a commercial vendor (decay time 1.9 ps) and in NIST's EEEL Division (365 fs decay). The carrier decay time fit (solid line) is approximately five times longer for the commercial film than for the EEEL material. We measure ~2 THz bandwidths for strip-line antenna systems using the commercial material and, from the lifetime decrease, bandwidths of up to ~12 THz may be achievable with the EEEL material. These measurements demonstrate the critical need to monitor temperature during deposition (achieved in the EEEL apparatus) and that measured lifetimes correlate with desired frequency response for THz antenna systems. (E. Heilweil and A. Migdall)

■ **Colorimetric Characterization of Special-Effect Pigment Coatings.** The Division, with ATP support, is developing methods for the quantitative characterization of special-effect pigment coatings, such as pearlescent coatings, important for the appearance of many commercial products, including automobiles, cosmetics, and various consumer goods. The complexity of these coatings increases the need for better appearance measurements for process and quality control.

Pearlescent coatings typically consist of thin metal-oxide-coated transparent mica platelets (see fig. 16). Constructive and destructive interference of light from the front and back surface reflections of these platelets are responsible for the chroma, hue, and brightness variation with the angles of incidence and viewing.

To quantify the properties of the pearlescent coatings, a series of samples supplied by manufacturers were examined using the Division's Spectral Tri-function Automated Reference Reflectometer (STARR). STARR measured the reflectance of the samples for incident wavelengths from 380 nm to 780 nm in 10 nm increments and incident angles of 15°, 25°, 45°, 65°, and 75°. Viewing angels were chosen from –80° to 80° in 5° steps. For each pair of incident and reflected angles, colorimetric values of lightness, *a*, *b*, hue, and chroma were determined. The STARR-determined colorimetric quantities validated the qualitative expectations by exhibiting a strong dependence on the incident and reflected angles. Empirically, it is found that measurements at a subset of the reflectance angles, 15°, 35°, 45°, 70°, and 85°, for each incident angle, provide a complete characterization of the coatings.

Future efforts are directed at developing improved light scattering models to predict the optical properties of special-effect coatings, using recent experimental data on idealized coated samples for validation. (M. Nadal and T. Germer)

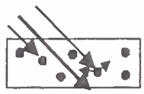
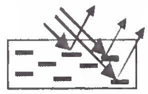
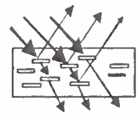
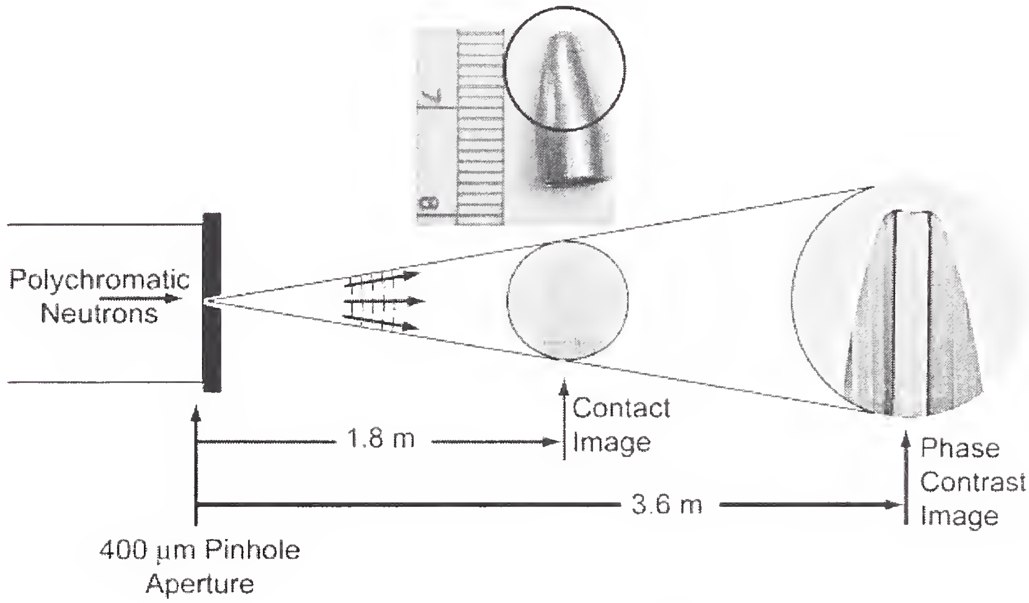
Type of pigment	Absorption	Metallic	Pearlescent
Optical principle of pigments (first order)	 Absorption and/or difuse scattering	 Specular reflection	 Thin-film interference
Perceived chroma and hue	Independent of geometry	Independent of geometry	Dependent on geometry
Perceived brightness	Independent of geometry	Dependent on geometry	Dependent on geometry
Measurement geometry	0°/45° or ~0°/d	45°/15°, 45° & 110°	Under study

Figure 16. Illustration of scattering mechanisms, perceptions, and measurement geometries for various types of common pigmented coatings. ❑

IONIZING RADIATION DIVISION



Overleaf

Phase Contrast Image: Shown are two different kinds of neutron images of a lead casting. Lead castings are examples of objects in which internal structures are not clearly revealed in either conventional x-ray images or in conventional (contact) neutron radiographs. The Contact Image, which was taken by placing the neutron detector plate directly behind the casting, shows very little contrast. However, in the Phase Contrast Image, which was taken with the detector plate 1.8 m downstream from the casting, the imaging of internal features has been greatly enhanced by wave interference.

IONIZING RADIATION DIVISION

OVERVIEW

The Ionizing Radiation Division of the Physics Laboratory supports the NIST mission by 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 the fundamental physical interactions of ionizing radiation with matter;
- operates two user facilities at the NCNR cold neutron guide hall for researchers from industry, universities, and national laboratories on neutron radiography, weak interaction physics, and fundamental quantum phenomena in neutron interferometry;
- develops improved methods for radiation measurement, dosimetry, and 2- and 3-dimensional mapping of radiation dose distributions;
- develops primary standards and transfer standards for radioactive sources used in therapy;
- 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 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).

PROGRAM DIRECTIONS

■ **Brachytherapy Source Dosimetry.** Brachytherapy (treatment with sealed radioactive sources) has seen a tremendous increase in the use of low-energy photon emitting seeds for prostate cancer and the introduction of intravascular brachytherapy, using beta-particle- (and photon-) emitting sources to inhibit arterial restenosis (re-closing) following balloon angioplasty. In both cases, NIST responded to the needs of the manufacturers, regulators and clinical physicists by developing new standards and measurement methods to calibrate the quantities needed to ensure accurate dosimetry for the wide variety of sources introduced, and disseminating these standards through a network of secondary calibration laboratories.

■ **Diagnostic X-Ray Beam Dosimetry.** Dosimetric measurement standards, in terms of air-kerma (or exposure) for x-ray beams from 10 kVp (x-ray source accelerating potential in kilovolts) to 300 kVp are developed and maintained at NIST, and disseminated to manufacturers and the medical physics community in North America through a network of secondary calibration laboratories. NIST maintains more than 75 beam qualities for conventional (W-anode) x-ray beams, and 17 beam qualities for mammography (Mo- and Rh-anode) x-ray beams.

■ **Standards and Calibrations for Radiation Therapy Dosimetry.** More than 600,000 cancer patients per year are treated in the US with radiation beams, mainly from high-energy electron accelerators (either directly with the electrons or converting to high-energy x rays). NIST maintains and disseminates the standards for air kerma (exposure) and for absorbed dose to water from ^{60}Co gamma-ray beams, the basis for calibrating instruments used to measure the absorbed dose delivered in therapy beams.

■ **Standard Reference Data on Radiation Interactions.** NIST has nearly five decades in the development of critically evaluated, comprehensive databases of cross-section information for ionizing photons (x and gamma rays), electrons, and heavy charged particles. These data are often adopted by national and international standards organizations for use in radiation protection, medical therapy, and industrial applications. This work continues in the Division's Photon and Charged-Particle Data Center.

■ **Theoretical Dosimetry and Radiation Transport Calculations.** The radiation transport and Monte Carlo methods pioneered and developed at NIST to calculate the penetration of electrons and photons in matter are used in most of the major codes today. Monte Carlo simulation is increasingly applied to problems in radiation metrology, protection, therapy and processing as an accurate tool for design, optimization, and insight often inaccessible to measurement.

■ **Radiation Processing Dosimetry.** NIST has been a world leader in the dosimetry for the high levels of absorbed dose used in the industrial radiation processing of materials (e.g., polymer curing, sterilization of single-use medical devices, food irradiation, and destruction of biological weapons). Accurate transfer dosimetry is increasingly done on the basis of alanine/EPR dosimetry, rather than the radiochromic film dosimetry developed at NIST, and a new NIST system is near completion for on-demand, internet-based *e*-calibrations for industry, based on alanine/EPR dosimetry.

■ **Radiation Protection Dosimetry.** NIST exposure standards for x-ray beams and gamma-ray sources are the basis for the radiation dosimetry monitoring of workers in the U.S. We are currently developing an instrument calibration service for low exposure rates of ^{137}Cs (down to tens or hundreds of iR/h). Our program in retrospective tooth-tissue/EPR dosimetry is now supporting a number of epidemiological studies.

■ **Radiation Source Facilities and Characterization.** NIST maintains a 7 MeV to 32 MeV electron linac in its Medical Industrial Radiation Facility (MIRF), along with 4 MV Van de Graff and 500 keV electrostatic accelerators. These are used in a variety of radiation applications, including the current development at MIRF of a High-Energy Computed Tomography (HECT) facility. Plans are to acquire a clinical medical linac to support the development of therapy-level dosimetry calibrations.

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

■ **Magnetically Trapping Ultra Cold Neutrons.** In collaboration with physicists at Harvard University, superthermal production of ultracold neutrons (UCN) in superfluid helium and magnetic trapping of these neutrons have been successfully demonstrated. Several kinds of upgrades to the trap are in progress to increase the number of trapped neutrons and to reduce background events which mask the observation of neutron beta decay in the trap. The initial application of this UCN source will be a neutron lifetime measurement with a potential improvement in accuracy of better than a factor of 10 compared to the present best value.

■ **Neutron Fields for Materials Dosimetry and Personnel Dosimetry.** A diverse array of well-characterized and documented neutron fields is maintained for calibrations and for development of methods for materials dosimetry and personnel dosimetry. A new generation of staff has taken over these activities with continuing guidance from emeritus staff members, who are serving on contract or as guest researchers. The application of calorimetry to absolute neutron counting is being pursued to validate and improve on traditional methods of fluence measurement and neutron source calibration.

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

■ **Neutron Imaging for Fuel Cell Research.** Neutron tomography and real-time radiography are being applied to the observation of hydrogen and water transport in operating fuel cells and to other industrial applications. 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. New developments in phase-contrast imaging in large beams without the need for an interferometer are also being pursued.

■ **Polarized ^{3}He-based Neutron Spin Filters.** We are currently applying neutron spin filters based on polarized ^{3}He to materials science and fundamental physics with neutrons. We produce the polarized gas by either of two optical pumping methods, known as spin-exchange and metastability-exchange. Both continue to be improved for the needs of neutron applications. We have employed spin filters for experiments on the small angle neutron scattering spectrometer (SANS) and we are also pursuing application to neutron reflectometry at the NCNR and Argonne National Laboratory. For fundamental physics, we produce unique cells for a parity violation experiment at Los Alamos.

■ **Radionuclide Standards for Nuclear Medicine.** The development of a standard for the α-emitting radiotherapy nuclide ^{211}At will be the highest-priority project for the radiopharmaceutical standards program during the present fiscal year. Other important projects include the investigation of geometrical effects in measuring nuclides such as ^{177}Lu and ^{166}Ho in vials and syringes.

■ **Radionuclide Metrology Development.** A pulse recording technique has been developed which will permit a given data set to be analyzed *ex post facto*. Intercomparison of the results of various types of analytical reductions on the same set of data will be possible and become routine, which will lead to reduced systematic uncertainties and very much faster measurements.

■ **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 has been based on participation in regulation driven performance evaluation programs of limited scope. The fundamental flaw that the metrology community recognizes is that there is a lack of direct linkage to the national radioactivity standards. This situation is being addressed in the publication of three ANSI Standards. These three consensus standards call for a traceability testing program that links the quality of operational measurements to the national standards. The Radioactivity Group has established such a traceability testing program for low-level radiochemistry laboratories such as: Westinghouse Carlsbad, University of New Mexico at Carlsbad, Sandia National Laboratory, and EPA Montgomery.

■ **Criteria for Production of QC Materials.** NIST, in collaborations with DOE/EM, NRC, NIST, FDA, universities, utilities, national laboratories, instrument manufacturers, commercial radioactivity standards companies, and commercial proficiency evaluation companies initiated the process of establishing consensus criteria for the production of QC materials as a sub-issue to its traceability priority. This issue is of major importance because material quality is critical to the credibility of PE programs/analytical results, and is fundamental to other issues.

■ **Virtual Radiobioassay Standard Phantom.** Exposure of occupational (weapons production, environmental clean-up, nuclear power generation, and waste management) personnel and the public to radioactive sources is non-invasively evaluated by external gamma-ray measurement. NIST is being asked to develop standard phantoms containing radionuclides as a calibration reference for the gamma-ray measuring instruments.

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

■ **Environmental Management and Nuclear Site Remediation.** Resonance Ionization Mass Spectrometry continues to be developed with improvements in sensitivity and selectivity based on several factors such as lowering of the background, careful choice of excitation scheme, development of a graphite furnace source, and incorporation of a non-axial-beam geometry. The Nuclear Regulatory Commission is moving toward increasing sensitivity requirements for *in situ* measurements.

■ **Radionuclide Speciation in Soils and Sediments.** While regulators and the public are interested in assuring that radionuclide decontamination in the environment is cost-effective and thorough, the underlying basis for soil and sediment decontamination is the speciation of the radionuclides. 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 distribution of radioactive elements in soils and sediments.

MAJOR TECHNICAL HIGHLIGHTS

■ **Calibration of Low-Energy Photon Brachytherapy Sources.** Small radioactive "seed" sources used in prostate brachytherapy, containing either the radionuclide ^{103}Pd or ^{125}I, are calibrated in terms of air-kerma strength using the NIST Wide-Angle Free-Air Chamber (WAFAC). The WAFAC is an automated, free-air ionization chamber with a variable volume that directly realizes air kerma (or exposure). Seeds of twenty different designs from fourteen manufacturers have been calibrated using the WAFAC. On-site characterization at seed manufacturing plants for quality control, as well as at therapy clinics for treatment planning, relies on well-ionization-chamber measurements. Following the primary-standard measurement of air-kerma strength, the responses of several well-ionization-chambers to the various seed sources are determined. Such response factors enable well-ionization-chambers to be employed at therapy clinics for verification of seed air-kerma strength, a quantity used to calculate dose rates to ensure effective treatment planning.

To verify that seeds of a given design calibrated at NIST are representative of the majority of those calibrated in the past, several additional tests have been implemented. Mapping the distribution of radioactive material within a seed using radiochromic-film contact exposures as well as angular x-ray emission measurements enable characterization of the degree of anisotropy present in seed emissions. The relative response of calibration instruments has been observed to depend on such anisotropy. Data from two Accredited Dosimetry Calibration Laboratories (ADCLs) and the seed manufacturer, in addition to the results of NIST measurements, are compiled and checked as a function of time to ensure the continuous validity of the calibration traceability chain from NIST to ADCLs and manufacturers and to the clinic. (M.G. Mitch, P.J. Lamperti, S.M. Seltzer, and B.M. Coursey)

■ **X-Ray Spectrometry of Prostate Brachytherapy Sources.** To understand the relationship between well-ionization-chamber response and WAFAC-based air-kerma strength for prostate brachytherapy seeds, x-ray emission spectra are measured with an HPGe detector. Pulse-height distributions from the spectrometer are unfolded to obtain the true photon spectra emerging from the seeds in the transaxial direction. ^{103}Pd seeds from all five manufacturers emit very similar photon spectra, while there are five distinct spectra emitted by ^{125}I seeds from thirteen manufacturers. These differences in ^{125}I seed emission spectra are a result of fluorescence x-rays emitted by the radionuclide support material, either silver or palladium. The effect of these fluorescence x-rays is to lower the average energy of the emitted spectrum, resulting in a lower well-ionization-chamber current relative to air-kerma strength because of the greater energy sensitivity of the well-chambers compared to that of the WAFAC. Knowledge of seed emergent spectra allows separation of well-ionization-chamber response effects due to spectral differences from those due to seed internal structure and self-absorption. (M.G. Mitch, S.M. Seltzer, and P.J. Lamperti)

■ **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, also used to characterize sources in the cylindrical geometry for transaxial uniformity. In addition, irradiations of planar sheets of film at various depths in water-equivalent plastic are used to construct data sets which can be used to predict the dose rate at arbitrary locations around the sources using a modified form of the AAPM Task Group 43 Protocol. The equipment used for these studies is augmented with two micro-scintillator detection systems, two automated three-dimensional water-tank scanning systems, various well-ionization-chambers, and two small fixed-volume ionization chambers.

Collaborations were continued between NIST and Guidant, Inc., for dosimetry of their ^{32}P wires, and over 350 of their well-ionization-chambers were calibrated. Collaborations also continued with Novoste, Inc., for dosimetry of ^{90}Sr/Y seed trains, and a measurement-assurance proficiency test was performed with two AAPM secondary laboratories for these sources. Collaborations were inaugurated with Radiovascular for the calibration of their ^{32}P shell source, and with Medtronic and with Xoft for the calibration of their miniaturized x-ray sources. Coupled with the continuing collaboration with Photoelectron Corporation for the calibration of their x-ray probes, it is anticipated that these collaborations will lead to a new standard for low-energy photon absorbed dose measurement.

A new collecting electrode with a much better defined collecting area was designed for the NIST extrapolation chamber. Successful construction of this electrode is expected to reduce the current large uncertainty in the NIST calibration of beta-particle brachytherapy sources. (C.G. Soares and M.G. Mitch)

■ **Beta-Particle-Emitting Ophthalmic Applicator Calibration Service.** With the advent of the calibration service for ophthalmic applicators at the University of Wisconsin Accredited Dosimetry Calibration Laboratory, the role of NIST in these routine calibrations has diminished considerably. NIST's role in this field will be more geared towards providing transfer standard sources and fields both to secondary laboratories and source manufacturers. The results of the major international intercomparison of ophthalmic applicator dosimetry, which included the dosimetry of both curved and flat sources of ^{90}Sr/Y and ^{106}Ru/Rh was published in Medical Physics and are included in the ICRU report on beta particles for medical applications. A new high-sensitivity electrometer has been purchased to allow measurement of lower activity sources with this system. An intercomparison on high-dose-rate beta-particle dosimetry between NIST and PTB was begun using a PTB secondary standard. (C.G. Soares and M.G. Mitch)

■ **Development of a New X-ray kV Calibration Service.** The NIST Ionizing Radiation Division is in the process of developing a new x-ray beam kV calibration service. The plan is to offer calibrations of devices used to measure the accelerating potential applied to x-ray generators. A precision voltage divider, calibrated by EEEL and traceable to the NIST primary standard for voltage, will be installed on the x-ray generators used in the NIST x-ray beam calibration range, covering constant accelerating potentials up to 300 kV. Customers can submit devices to be irradiated in NIST beams of their choice. Such devices usually are based on some indirect measurement, such as the differences in transmission among x-ray filters of different compositions and/or thicknesses. The results from the device will be reported along with the measured accelerating potential, with an accuracy anticipated to be typically 1 kV or better at the 95 % confidence level. (C.M. O'Brien)

■ **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 for attenuation coefficients for x rays and gamma rays, including cross sections for Compton and Rayleigh scattering, atomic photo-effect, and electron-positron pair production, as well as on energy-transfer, energy-absorption and related coefficients needed in radiation dosimetry. Work on charged-particle cross sections and radiation transport data includes 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. A new evaluation of cross sections for the elastic scattering of electrons and positrons by neutral atoms has recently been completed. Current efforts are focused on the development of a suite of computer programs to evaluate the differential, total, and energy-loss cross sections for Compton scattering of photons from electrons bound in atoms.

The quality of the work of the Data Center is reflected in the use of our data in engineering and scientific compendia, books and review articles, and in the reports and protocols of national and international standards organizations. Our data and Monte Carlo transport algorithms are incorporated into the most widely used general-purpose radiation transport codes. We have used two Monte Carlo codes for calculations of the wall-correction factors for the NIST graphite-wall cavity-ionization chambers that serve as the U.S. standard for gamma-ray air kerma and exposure. The results will be used to modify these U.S. standards in the near future, in concert with many other national primary standards laboratories around the world. (S.M. Seltzer, P.M. Bergstrom, J.H. Hubbell, and M.J. Berger)

■ **Internet-Based Calibration Services for the Radiation-Processing Industry.** An Internet-based calibration service has been built for fast remote calibration of high-dose radiation sources against the U.S. national standard gamma-radiation source. The new service will electronically deliver calibration results to the industry customer, on-demand and at a lower cost. The industrial site will have a dosimeter reader and an Internet link to the NIST server. When a calibration is requested, the industrial site will connect to the NIST calibration web site and initiate the process. In order to ensure a reliable dose assessment, the NIST server will lock-out the local user and fully control the measurements remotely. The remote control process will include the spectrometer calibration, setting of readout parameters, real-time spectral acquisition and validation. The post-measurement evaluation process involves a rigorous verification of the quality of the acquired spectra, and dose calculations from calibration curves maintained at NIST. The system has been demonstrated at national and international dosimetry symposia. Current efforts include further refinements in software/hardware compatibility and development work with future industrial partners. (M.F. Desrosiers, V. Nagy, and J.M. Puhl)

■ **Validation of the EPR Method for Tooth-Enamel Dosimetry.** Knowledge is required on dose-effect relationships for radiation-induced stochastic and deterministic effects. Therefore, the acquisition of dosimetric effects from populations with chronic exposure is of special interest (Chernobyl, Techa River, etc.). 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 is essential before these data can be used reliably in epidemiological studies from which recommendations are made for occupational exposures. Significant effort has gone into developing sound protocols for the preparation of tooth-issue sample for EPR analysis, and into the analysis and interpretation of the EPR results. Results have been obtained for members of the Techa riverside population from 1945-1949, exposed to radioactive waste from the Mayak nuclear weapon plant near the Techa River, Urals, Russia. (A.A. Romanukha, M.F. Desrosiers, and V. Nagy)

■ **Calibration of Beta-Particle Sources and Instruments for Radiation Protection.** A calibration service for protection-level beta-particle sources and instrumentation has been in place for several years. The measurement system is automated, and capable of measuring extremely low absorbed-dose rates. The second-generation beta-particle secondary standard system (BSS2), which includes the isotope ^{85}Kr, is now utilized routinely for calibrations and research into standard extrapolation-chamber data-handling techniques. The sources were calibrated both at the Physikalisch Technische Bundesanstalt (PTB) and at NIST, allowing a direct intercomparison of calibrations. The systems are also being used for the dosimetry characterization of a photo-stimulatable-luminescence-phosphor imaging system. The standardized techniques developed at PTB and NIST are now included in an International Organization for Standardization (ISO) draft standard and are being implemented in the NIST calibration service. A new high-sensitivity electrometer has been purchased to replace the 15-year old high-sensitivity electrometer currently being used for these measurements. (C.G. Soares and M.G. Mitch)

■ **Gamma-Ray Sources for Radiation-Protection Calibrations.** Five gamma-ray sources are used for calibration of instruments and passive dosimeters, in terms of air-kerma and exposure, to support protection-level measurements in the U.S. The calibrations are directly traceable to measurements with the national primary standard for gamma-ray exposure, graphite-cavity ionization chambers. The ranges provide a wide range of air-kerma rates. Two ^{137}Cs sources provide air-kerma rates from 4.5 mGy/h to 110 mGy/h; a third ^{137}Cs source provides air-kerma rates of 2.3 Gy/h and 3.6 Gy/h; and two ^{60}Co sources provide air-kerma rates from 0.25 mGy/h to 5.4 mGy/h. Programs of regular, calibrated exposures of thermoluminescent dosimeters provide direct support for the worker-protection measurement programs of a number of agencies, including the U.S. Navy. NIST standards are also disseminated through a number of secondary instrument-calibration laboratories to provide traceability of protection-level measurements. Work is underway to develop a calibration capability at much lower air-kerma rates, down to 5 ìGy/hr. (R. Minniti, P.J. Lamperti, and J. Shobe)

■ **Fundamental Neutron Physics – User Facility and In-house Program.** The Neutron Interactions and Dosimetry (NID)Group supports a national user facility for research in fundamental neutron physics. Our collaborators and customers represent institutions in at least 11 different states and 7 other countries. (J.S. Nico, P.R. Huffman, M.S. Dewey, T.R. Gentile, A.K. Komives, and A.K. Thompson)

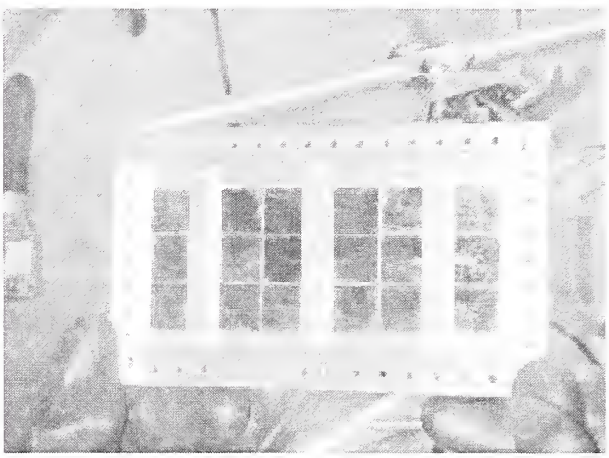


Figure 1. The tiled assembly of intercalated graphite is seen as it is held by gloved fingers within an inert atmosphere chamber.

Two separate measurements of the beta-decay lifetime of the neutron have been our primary focus during the past year. In one experiment, the decay rate of magnetically trapped ultracold neutrons (UCN) will be measured to extract the neutron lifetime. This experiment is led by Harvard University and recently the techniques were demonstrated in a proof-of-principle measurement. The apparatus has been upgraded in preparation for a lifetime measurement. The major improvement this year was the development, fabrication and testing of a neutron monochromator made of potassium-intercalated graphite (KC_{24}). This monochromator allows neutrons with wavelengths near 0.9 nm to be Bragg reflected from the primary beam with greater than 85% reflectivity, allowing for a significant suppression of background events from neutrons with other wavelengths. The monochromator assembly consists of nine pieces of KC_{24} that must be encapsulated in an inert atmosphere to minimize the chemical reactivity of the potassium with air (see fig. 1). The assembled monochromator has been completely characterized and is performing well above initial expectations. Also note that the 0.9 nm wavelength is about a factor of two longer than that of any other monochromatic beam in the NCNR facility, and the NCNR management and material scientists are in the process of replicating this technology for instruments in the facility. (P.R. Huffman)

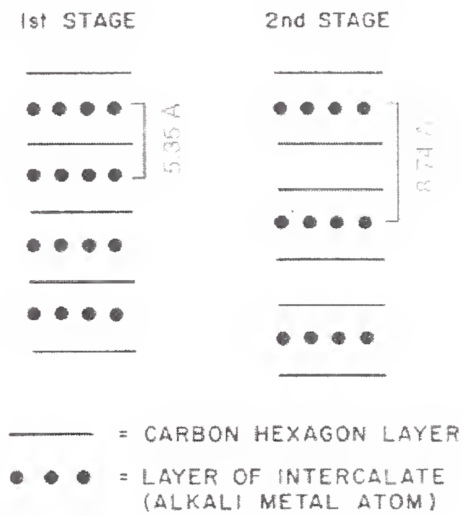


Figure 2. The diagram shows stages of intercalation within the hexagonal close-packed structure of crystalline graphite. The KC_{24} compound is denoted as a "2nd stage" compound because it has potassium in every other layer. The large spacing of the potassium layers produces a long wavelength monochromator.

The other lifetime experiment, which is led by NIST staff, measures the neutron decay rate in a beam passing through a well-defined volume. The key components are a Penning-trap to confine the decay protons and a high-precision neutron monitor to measure the average number of neutrons within the trap volume. The methods and associated systematic uncertainties in this experiment are completely different from that of the UCN lifetime experiment, so that consistent results from the two different types of experiments will constitute a very reliable determination of this important quantity. The result to be submitted for publication from this Penning-trap experiment is approximately $\tau_n = 885\ s \pm 4\ s$. The four-second uncertainty should be reduced to ± 2 s once cross-calibrations can be performed among the high-precision neutron monitor and two other "black" neutron counters. The refinements in neutron counting from these calibrations are also of interest in verifying the neutron emission rate from the standard neutron source NBS-I, which is the basis for two of our calibration services and much of our neutron dosimetry work. (M.S. Dewey and J.S. Nico)

■ **Neutron Interferometry and Optics Facility (NIOF) – User Facility and In-house Program.** The NIOF is the other national user facility operated by the NID Group. Radiography and tomography services and research involve both academic and industrial customers and collaborators.

Initial measurements were completed this year on the coherent neutron scattering lengths for hydrogen, deuterium, and ^{3}He. Preparation of publications is still in progress, but the data analysis is essentially complete. The estimated uncertainties from these new measurements are about a factor of ten lower than those of the best preceding measurements. These data are of interest for theoretical studies of "few-body" interactions (6 quark, 9 quark, and 12 quark), and also for Los Alamos stockpile-stewardship calculations. All of these were measurements on gaseous samples at pressures of several atmospheres.

A complete set of measurements was also made this year in an innovative approach to the measurement of the neutron-electron scattering length, by observing the large phase shifts as a thin silicon crystal was rotated through the Bragg angle within a neutron interferometer. The neutron-electron scattering length is related to the distribution of electric charge within the neutron and the mean square charge radius of the neutron (which has a net charge of zero). A precise value of this rather fundamental quantity is also of interest in the theory of few body nuclear systems and related precision measurements.

Development of neutron radiography and tomography facilities is continuing, with work now concentrating on the BT-6 beam position, which has just been granted for this purpose by the NCNR management. Accomplishments this year included near real-time imaging of water formation in an operating fuel cell, a tomographic image of a fuel cell, and a radiograph showing lithium ion transport in a commercial battery. (M. Arif and D.L. Jacobson)

■ **Polarized ^{3}He for Neutron Spin Filters.** The primary focus of the polarized ^{3}He program is the development of neutron spin filters and application of these devices to both materials science and fundamental physics. We are developing two optical pumping methods, spin-exchange and metastability-exchange, for producing the polarized ^{3}He gas. We are also contributing to an experiment in weak interaction physics at Los Alamos National Laboratory to measure parity violation in the reaction $n+p \rightarrow d+\gamma$. In addition, we are collaborating with Indiana University in applications at the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory.

The most important development this year was the production of large diameter cells with very long polarization lifetimes for both optical pumping methods. Spin-exchange optical pumping is most efficient in small volume, high pressure (3 bar to 10 bar) cells, primarily because of the reduced number of rubidium atoms and to a lesser degree because of better spectral overlap with broadband diode lasers. However, construction of the large-diameter glass cells needed for typical neutron beams, is difficult (and hazardous) at such pressures.

Recently, we have tested spin-exchange cells at near-atmospheric pressure and found that with sufficient laser power, polarization comparable to that obtained in higher pressure cells can be obtained in these cells. Operation at such low pressure has an additional advantage: because of the reduced dipole-dipole relaxation at lower pressure, we have been able to achieve polarization lifetimes as long as one month, about two to three times longer than had ever been achieved for spin-exchange cells previously. In addition, the long lifetime permits higher polarization at a given laser power.

Our low-pressure cells are expected to be employed as the polarizer for the $n+p \rightarrow d+\gamma$ experiment, as well as having important utility for material science and other fundamental physics experiments. The success of our apparatus for the preparation of sealed spin-exchange cells has also led to the production of two refillable cells for the metastability-exchange method with 200 h lifetimes. Our development of lower pressure cells was an indirect outgrowth of tests of spectrally-narrowed high power diode lasers, developed by collaborators at the University of Wisconsin. (T.R. Gentile and A.K. Thompson)

Neutron Dosimetry. Section III (neutron measurements) of the Consultative Committee on Ionizing Radiation (CCRI) is currently carrying out three international comparison exercises, and we are participating in all of them. NIST is leading a comparison of thermal neutron fluence measurements; the PTB is leading a comparison of fast neutron fluence measurements; and the National Physical Laboratory (NPL, Teddington) is leading a neutron source emission rate comparison.

For the thermal neutron comparison, we prepared a transfer instrument system based on an active ^{10}B ionization chamber. This system was used successfully for the comparison measurements at the NPL, but one problem with an electrical contact had to be resolved. The system was returned to NIST for a check on the integrity of the ^{10}B deposits and will be sent on to China and Japan next year, if international shipping restrictions permit.

Measurements of neutron inelastic scattering in steel have been made in collaboration with Ohio University and Penn. State. These measurements are needed to better understand data for nuclear reactor pressure vessel damage estimation. Initial measurements with a spherical shell of 4 cm thickness were recently reported at the Nuclear Data 2001 meeting in Tsukuba.

Calibration services for radiation protection dosimetry and neutron source emission rate measurement continued at a fairly busy pace. (J.M. Adams, A.K. Thompson, J.S. Nico, and D.M. Gilliam)

Nuclear Cross Section Standards. The neutron cross section standards are important since almost all cross sections are measured relative to them. Any improvement in a cross section standard leads to improvement in all measurements that have been or will be made relative to that standard. The NIST neutron cross section standards project has played a significant 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, detailed examination of the standards database, and pursuing the extension of the standards over a larger energy range.

This work is taking place through participation in the U.S. Cross Section Evaluation Working Group (CSEWG) and two international committees, the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency Nuclear Science Committee (NEANSC). The NIST representative heads a standards Task Force of the CSEWG, coordinates a Subgroup on standards of the Working Party on International Evaluation Cooperation of the NEANSC, and was chairman of an IAEA Consultants' Meeting on Improvement of the Standard Cross Sections. Final approval was recently obtained for an IAEA Coordinated Research Project which will provide resources to allow meetings of the contributors to the standards evaluation process. 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.

This NIST project 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. The final results of the data indicate differences with the most recent U.S. evaluation of this angular distribution. The work was accepted for publication in the Physical Review. (A.D. Carlson and P.R. Huffman)

Development of a Radiotherapy Nuclide Standard. In an effort to solve the problem of distributing a standard of the short-lived ($t_{1/2}$ = 17 h) nuclide, ^{188}Re, which is of interest in many areas of nuclear medicine, we have standardized solutions of ^{188}Re in equilibrium with its parent nuclide, ^{188}W. This will provide researchers the ability to calibrate their instruments for both of these radionuclides with a relatively long ($t_{1/2}$ = 64 d) source of activity. A series of ampoules was prepared from a stock solution and measured in several different types of ionization chambers in order to determine calibration factors for these instruments. Primary activity determinations were made using liquid scintillation (LS) counting with the CIEMAT/NIST ^{3}H-standard efficiency tracing method. Using the data from the sources deemed to be stable, the activity of the stock solution was determined with an expanded ($k = 2$) uncertainty of 0.74%. Calibration factors were determined for all of the ionization chambers in the standard NIST geometry of 5 mL of liquid in a flame-sealed ampoule. (B.E. Zimmerman, J.T. Cessna, and M.A. Millican)

Calibration of Intravascular Brachytherapy Sources. Considerable work has continued on providing NIST-based activity calibrations for manufacturers of intravascular brachytherapy sources.

In the past year, two sets of nondestructive ionization-chamber-based calibrations were performed for ^{32}P "hot-wall" angioplasty-balloon catheter sources that are manufactured by Radiance Medical Systems Inc. (Irvine, CA), and also for a set of seeds from the Novoste Corporation (Norcross, GA). The seeds are stainless-steel-encapsulated, ceramic-based ^{90}Sr-^{90}Y sources whose calibration factors were also derived from earlier destructive radionuclidic assays by NIST. (R. Collé)

Destructive assays were also performed for a Belmont, California company, IsoStent, which has developed a stainless steel stent containing the beta emitter phosphorus-32. The stents were first intercompared in a NaI well crystal γ-detector, looking at the emitted bremsstrahlung. A subset of the stents were then slowly digested in a small volume of carrier solution, with the addition of a few drops of concentrated hydrofluoric acid. The expanded ($k = 2$) uncertainties on the activities were on the order of 1.1 % to 2.1 % for the digested stents and 1.5 % – 2.6 % for the undigested stents. (J.T. Cessna)

The results of all of these calibrations were used by these companies for internal quality control and to transfer the NIST calibrations to other manufacturing facilities and to two calibration laboratories in Europe.

■ **Development of Radioactivity Standards for Alpha-Emitting Radiotherapy Nuclides.** We are continuing to work with the National Institutes of Health PET Department and Clinical Center to develop a standard for a potential radiotherapy nuclide, the α-emitter ^{211}At. To date, a measurement protocol for determining contained activity has been developed using 4π (α/EC) liquid scintillation counting with efficiency tracing, which will give an expanded ($k = 2$) uncertainity of about 1 %. A final set of experiments is planned that will determine a dose calibrator dial setting for this nuclide in at least one standard geometry. (B.E. Zimmerman, J.T. Cessna, and M.A. Millican)

■ **Development of ^{166}Ho-DOTMP Secondary Standard.** The same decay scheme properties of the rare-earth nuclide ^{166}Ho that make it attractive as a therapeutic radionuclide also make it necessary to take care when measuring the radionuclide with an ionization chamber. In order to develop calibration factors for a variety of ionization chambers in specific, clinically relevant geometries, two sets of calibration experiments were performed on solutions of ^{166}Ho-DOTMP, which is the final the drug product form. These solutions were supplied by ABC Laboratories using materials from Missouri University Research Reactor (both located in Columbia, MO). NIST 5 mL ampoules were prepared for measurement on the NIST chamber "A," an NPL ionization chamber, the commercial dose calibrators residing at NIST, and commercial dose calibrators belonging to the companies involved in the calibration studies. Two different geometries at two different levels were also produced to determine calibration factors for the commercial dose calibrators. Standard samples of these geometries were also returned to the companies involved to check their in-house commercial dose calibrators. (J.T. Cessna, B.E. Zimmerman, M.P. Unterweger, L.R. Karam, and M.A. Millican)

■ **Cocktail Composition Effects on the Application of the CIEMAT/NIST Efficiency Tracing Method.** Liquid scintillation (LS) counting continues to be the method preferred by most metrology laboratories for performing quantitative assays of solutions containing beta-emitting radionuclides. Under many circumstances, there is little need to be concerned about the composition of the analyte solution, as most changes in detection efficiency arising from chemical effects can be accounted for by efficiency tracing against an established standard. However, there can be cases in which the solution composition can affect the efficiency in ways that cannot be accounted for using efficiency tracing techniques. We have performed a series of experiments aimed at identifying composition variables that influence LS cocktail stability and subsequent assay results for solutions containing ^{177}Lu or ^{188}W. (B.E. Zimmerman and J.T. Cessna)

■ **Radionuclidic Microcalorimetry for Absolute Radioactivity Standardizations.** This basic measurement capability has largely been re-established in the past year. Two different calorimeters have been put together and have been operating since October 2000; *viz.* a dual-compensated cryogenic calorimeter operating at a nominal 8 K (termed CAL hereafter) and a commercial isothermal microcalorimeter (IMC) operating at 303.5 K. (R. Collé and B.E. Zimmerman)

■ **Dissemination of National Standards of Radioactivity.** The Radioactivity Group disseminated the National Standards of Radioactivity mainly through the sale of over 650 Radioactivity Standard Reference Materials (SRMs), over 200 comparative measurements and Reports of Traceability and over 50 calibrations of customer sources. (L.L. Lucas, J.T. Cessna, and L.R. Karam)

■ **Calibrations of Large-Area Beta Sources.** Studies are continuing on the effects of beta-backscattering to develop a systematic method for determining the effective source thickness needed for relating the measured rate to activity. These determinations will be used to calibrate surface monitoring equipment in terms of radioactivity rather than emission rate. (M.P. Unterweger and P. Hodge)

■ **Reevaluation of the Half-Life of Tritium.** A remeasurement of the half-life of tritium has also been done and a reevaluation of the half-life using all reported values has been published. An accurate value for the half-life is very important in extending the useful lifetime of the tritium standards. (L.L. Lucas and M.P. Unterweger)

■ **Holmium-166m.** The large number of gamma rays, the wide energy range, and the long half life make ^{166m}Ho a very desirable gamma-ray source for determining the detection efficiency of germanium detectors and for monitoring their long-term stability. High-purity stable ^{165}Ho was neutron irradiated to produce ^{166m}Ho, which is now being calibrated in terms of activity and the gamma-ray emission probabilities and their uncertainties are being evaluated. (L.L. Lucas, B.E. Zimmerman, and L.R. Karam)

■ **Resonance Ionization Mass Spectrometry.** RIMS has been evaluated for measuring ^{135}Cs/^{137}Cs isotopic ratios. Spectroscopic measurements of 6s $^2S_{1/2}(F = 4) \rightarrow$ 6p $^2P_{3/2}(F = 5)$ transition frequency shifts for ^{135}Cs and ^{137}Cs confirmed existing values and demonstrated that it is possible to perform such measurements on sub-picogram samples. Optical isotopic selectivity of ~ 10^3 for both ^{135}Cs and ^{137}Cs against stable ^{133}Cs was observed and, when combined with a quadrupole mass spectrometer, overall selectivity of greater than 10^9 was demonstrated. (L. Pibida, L.R. Karam, and J.M.R. Hutchinson)

■ **International Equivalence**. As part of NIST's efforts in the international arena of measurement activities, the Radioactivity Group has prepared a listing of calibration capabilities for Appendix C (list of calibration and measurement capabilities, or CMC's) of the Mutual Recognition Arrangement and submitted it to our RMO. (L.R. Karam and L.L. Lucas)

■ **Mass Spectrometry for Environmental and Bioassay Measurements**. Accurate and precise analyses of low-level Pu isotopes are critical for environmental, radiobioassay, and nuclear safeguard programs. By actively producing Pu ions through thermal ionization rather than passively detecting Pu alpha decay, mass spectrometry not only has a capability of detecting ~10^6 Pu atoms but also determines its origin.

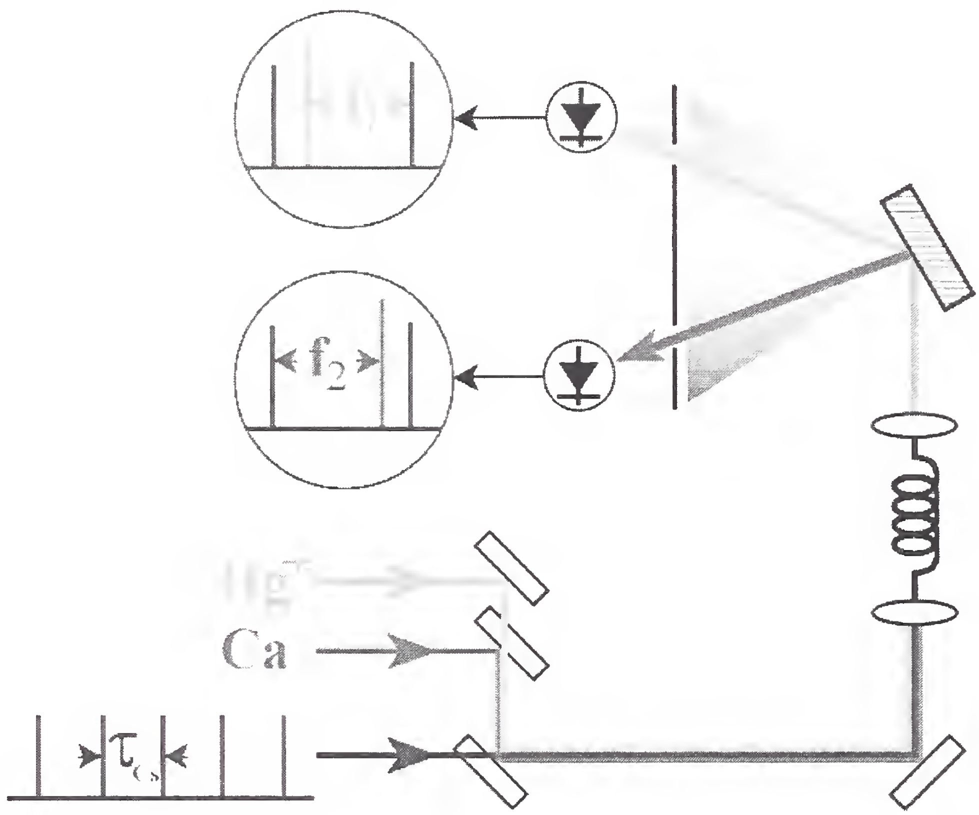
The production of Pu ions that may ultimately determine the measurement sensitivity, accuracy, and precision depends directly on sample deposition method. To optimize the efficiency, stability, and duration of Pu ion production, three deposition methods including direct deposition, electroplating, and resin bead loading were evaluated. The characteristics affecting the Pu ion production were compared for each method at a few picograms of ^{239}Pu and ^{240}Pu. The study showed that the best sample loading method for analyzing low-level Pu is to electroplate Pu onto Re filament surface. (Z.C. Lin and K.G.W. Inn)

■ **Second Intercomparison Study for Detecting μBq of ^{239}Pu in Urine by Atom-Counting Techniques.** To support the DOE's Marshall Island Resettling Program, we are assisting the DOE in identifying the most promising analytical techniques capable of quantifying Pu in urine at or below a level of ~20 μBq/L. Techniques including ICP-MS, FAT, AMS, and TIMS were evaluated for ^{239}Pu analysis under more realistic conditions by introducing environmental level of ^{240}Pu and natural U into urine samples. Also, more blank samples, a total of 8, are included to provide a better blank value estimate for ^{239}Pu. The test samples were prepared, verified, and sent to University of Utah, LLNL, and LANL for intercomparison measurement. The results from FAT, TIMS, and AMS have been evaluated. With completion of ICP-MS analysis, a full assessment of the four techniques will be reported. (Z.C. Lin and K.G.W. Inn)

■ **Radioanalytical Traceability.** By working with the American National Standards Institute's nuclear instrumentation N42 and N13 committees to establish criteria for radioanalytical traceability, three standards including ANSI N42.23, ANSI N42.22, and ANSI N13.30 have been published. Each of these standards were developed through consensus participation among industrial, commercial, utility, federal, state, national laboratory representatives to strengthen the credibility of national radioanalytical programs. ANSI N42.23 envisions the accreditation of reference laboratories that participate directly in a traceability-testing program with NIST, technical document reviews, and on-site assessments. These reference laboratories serve as traceability link between NIST and the service laboratories through their Performance Testing (PT) programs. The ANSI N42.22 standard provides additional and more specific criteria for source manufacturers and those reference laboratories producing PT materials. The criteria for the acceptance of testing results is $|V_R - V_N| \leq 3 \times (\sigma_N^2 + \sigma_R^2)^{1/2}$. That is the absolute bias between the reported value, V_R, and the NIST value, V_N, shall be less than or equal to three times the total propagated NIST uncertainty, σ_N, and the reported uncertainty, σ_R. It is the right hand side of the equation defines the "traceability limit" to the claimed traceability. ANSI N13.30 defines the traceability testing criteria for radiobioassay performance testing programs. It is anticipated that traceability testing for the reference laboratories supporting all aspects of traceability testing will be fully implemented in the future. (K.G.W. Inn, Z.C. Lin, Z.Y. Wu, and C. McMahon)

■ **NIST Radiochemistry Intercomparison Program (NRIP).** The program was implemented to assure the traceability of low-level radioanalytical measurements as defined in ANSI N42.22. Four years of performance data from fifteen participants were evaluated for ^{90}Sr, ^{238}U, ^{238}Pu, ^{240}Pu, and ^{241}Am at 0.03 Bq to 0.3 Bq per sample in water, air-filters, soil, synthetic urine, and synthetic feces. The relative mean difference from the NIST massic activity values across all matrices and radionuclides ranged from −1 % to −6 % with standard deviation of the means from 2 % to 7 %. Analysis of variance indicated that the analytical methods and sample matrix are the main factors causing bias in ^{241}Am and ^{90}Sr analyses, and ^{238}U analysis, respectively. About 90 % of the results were acceptable per the ANSI N42.22 criteria and an improvement in the participant's performance has been observed since the inception of the NRIP program. The majority of the failures to pass the ANSI N42.22 criteria were due to unrealistically small estimates of measurement uncertainties. Workshops have organized in assisting the NRIP participants with estimating their measurement uncertainties. (K.G.W. Inn, Z.Y. Wu, C. McMahon, and Z. Lin)

TIME AND FREQUENCY DIVISION



Overleaf

Femtosecond comb generator used to measure optical frequency: This picture shows schematically how a femtosecond comb generator is used to measure optical frequency. The output of the mode-locked femtosecond laser, with its repetition rate referenced to the cesium frequency standard, is input to the system along with the outputs of the optical frequencies to be measured, in this case spectral lines in mercury ions and neutral calcium. With the repetition rate locked to the cesium reference, the frequencies of all the modes of the comb are known. The signals go through a short piece of special non-linear optical fiber, which broadens the comb to cover more than a full octave. The beat frequencies between elements of the comb and the frequencies f_1 and f_2, then give the offsets of these frequencies from these comb elements, which are integer multiples of the cesium frequency.

TIME AND FREQUENCY DIVISION

OVERVIEW

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

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

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

PROGRAM 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, although this satellite service is scheduled to be terminated. The Division has completed an upgrade of the equipment and power level for WWVB. At a higher output power, these LF broadcasts are substantially more useful for mobile and consumer applications, because the antenna/receiver cost and size is 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 200,000,000 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 highly stable and reliable clock system that provides accurate time and frequency reference for services and applications and that serves as a reference for research on new standards and measurement methods. The reliability and stability of this time scale is based on the use of an ensemble of commercial cesium-beam standards and hydrogen masers combined under the control of a computer-implemented algorithm. The Division is working to advance the performance of the time scale through acquisition of more-stable clocks and improvement of electronic systems, which 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, which provide the practical realization of the definition of the second. Over the last several years, the Division has been operating two frequency standards. The first, NIST-7, 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 uncertainty for this standard is 5×10^{-15}. More recently, the Division has constructed and evaluated a cesium-fountain frequency standard, NIST-F1, which has an uncertainty of 1.2×10^{-15}, about three times smaller than that of NIST-7. The fountain concept, which uses laser-slowed atoms, provides longer atom observation times resulting in a narrower transition linewidth and smaller systematic frequency shifts. These two standards were operated in parallel for about two years, and were found to agree within their uncertainty statements. NIST-7 is now deemed to have served its purpose in this overlap period, and the Division will discontinue evaluations of its performance in order to place more emphasis on newer standards. Looking toward higher accuracy, the Division is studying standards based on trapped, laser-cooled atomic ions. Both microwave (40 GHz) and optical (ultraviolet-region) mercury-ion standards have been demonstrated, and while the microwave standard shows promise, the progress on the optical standard during this last year was so significant that work on the microwave standard has been slowed. When combined with the new optical-frequency-synthesis method described below, the new optical standard provides the means for measuring frequency from the near infrared through the visible portions of the spectrum. While the ion-storage program is already demonstrating prototype clocks, the work is generally treated as basic research providing the knowledge base needed for the development of future frequency 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 plans to place more emphasis on the two-way time transfer and GPS carrier-phase time-transfer methods that are becoming significantly more important for international time coordination and for comparisons of the new generations of frequency standards

■ **Optical Frequency Synthesis.** Over the last year, the Time and Frequency Division has been developing improved methods for optical frequency synthesis through frequency-comb generation with mode-locked (femtosecond) lasers. The Division has now demonstrated a system, which spans the spectrum from the near infrared to the visible. The uncertainties of measurements of the frequencies of optical transitions in mercury (at 282 nm) and calcium (at 657 nm), made recently using the femtosecond comb generator, are now limited by the uncertainty of the frequency of the cesium primary standard. This means that any frequency across the visible spectrum can be measured with an uncertainty approaching that of the primary frequency standard. An important consequence of this work is that the very-high-performance optical frequency standards developed over the last few years can now generate outputs in the microwave range. This opens up the possibility of a whole new generation of frequency standards and clocks with accuracies and stabilities well beyond that of the present primary standard.

■ **Optical Frequency Standards and Measurements.** Current optical-frequency standards such as the carbon-dioxide lasers, helium-neon lasers, and calcium-stabilized diode lasers already serve as references for supporting accurate spectroscopic measurements for industrial and scientific applications, but as indicated above, optical frequency standards will certainly have still broader impact. This is because higher-frequency transitions have better fractional-frequency uncertainty. Of particular importance will be laser-cooled ions (such as Hg^{+}) and neutral atoms (such as Ca). The projected accuracy of the laser-cooled ion standard goes well beyond that achievable with microwave standards. Aside from the work on optical standards, the Division is employing the new optical measurement methods described above to making improved optical frequency measurements important for secondary wavelength standards based on atomic-and-molecular transitions, advanced optical communication, analytical instrumentation, and length measurement. An important part of this program involves the development of diode laser systems, which can have very high spectral purity, tunability, simplicity, and low cost.

■ **Spectral-Purity Measurements.** The Division's development of spectral-purity measurements supports sound specifications for a range of aerospace and telecommunications 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. More recently, systems have been developed for making pulsed measurements, which are important for high-power systems such as radars. 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.** Finally, the Division is engaged in the application of time and frequency technology to important problems in sensing of trace impurities (pollutants) and quantum-limited measurements.

MAJOR TECHNICAL HIGHLIGHTS

■ **A New Generation of Frequency Standards.** Staff members of the Physics Laboratory in Boulder, in collaboration with T. Udem of the Max Planck Institute in Germany, have recently demonstrated an optical frequency standard with a microwave output, which in effect signals the introduction of a new generation of atomic clocks with potential performances well beyond those in operation today. This first demonstration of an optical clock with a microwave output, reported in the August 3 issue of Science, involves an optical frequency standard, with a Q factor (frequency divided by linewidth) of greater than 10^{14} coupled to a new optical-frequency synthesizer that bridges an octave in the optical spectrum and provides for a direct microwave output that is phase locked to the optical standard. The potential uncertainty of the optical clock is 1 part in 10^{18}, a factor of 1000 times better than today's best standards.

NIST staff members contributing to the development of this clock include J. Bergquist, A. Curtis, S. Diddams, R. Drullinger, L. Hollberg, W. Itano, D. Lee, C. Oates, K. Vogel, and D. Wineland.

Essential components of this standard include a single trapped mercury ion in a cryogenic trap, an ultra-stable laser used to probe the transition in the mercury ion, and a femtosecond laser system that produces a frequency comb spanning a full octave in frequency. The clock transition for the $^{199}Hg^+$ ion is at 1.064×10^{15} Hz. The ultra-stable laser is first locked to this mercury transition and then a single element in the comb is locked to the stable laser. Finally, the repetition rate (at about 1 GHz) of the femtosecond laser is stabilized by a self-referencing technique to provide a phase coherent linkage between the optical and the microwave range where cycle counting can be done. In comparisons with a laser-cooled calcium optical standard, an upper limit for the fractional instability of 7×10^{-15} was measured in a 1 second averaging interval, which is significantly better than that of the world's best microwave atomic clock. (J. Bergquist)

■ **Further Improvements to NIST-F1.** S. Jefferts and T. Heavner have made several improvements to NIST's cesium-fountain primary frequency standard NIST-F1, providing primarily for improved reliability of operation, but also resulting in improved accuracy. Reliability issues are important, since the value of NIST data submitted to the BIPM is substantially higher if data is submitted at regular intervals. Furthermore, the achievement of highly regular operation can offer the opportunity to use the data from this standard directly in the NIST time scale.

The improvements made to the standard include (1) the installation of new light shutters of substantially higher reliability, (2) the implementation of a servo-control system on the number of atoms tossed in each ball, (3) a lower noise quartz-crystal local oscillator, and (4) new software for the main line-center servo-control system. A completely new laser system (Ti:sapphire) has been acquired, and this will replace the current systems as soon as final acceptance testing is completed.

With these changes, the uncertainty of the standard has been improved from 1.7×10^{-15} to 1.3×10^{-15}. This latter evaluation number is the best yet reported to the BIPM. Furthermore, quantum-projection noise has now been observed at a level of 30 atoms. This is lower by a factor of 2 to 3 than has been previously seen in a fountain frequency standard. (S. Jefferts)

■ **International Frequency Comparisons.** T. Parker and J. Levine of the Division have improved both the two-way time transfer system and the GPS carrier-phase time transfer system allowing for more-routine international frequency comparisons with an added comparison uncertainty of 5×10^{-16} over intervals of 20 to 30 days. Continued improvements in these comparisons are needed to support comparisons of the fountain standards, which are clearly going to improve over the next few years.

The use of both of these systems has proven to be an essential aspect of this effort, since, in combination with time-scale date, each of the systems tends to uncover problems with the other. The day-to-day time stability for both systems is about 300 ps. Time comparisons at each end of a fixed time interval then result in a measurement of the relative average frequency over that time interval.

The best comparison made to date between fountain frequency standards at NIST and PTB show a frequency difference of 1.7×10^{-15} with a total uncertainty of 2.1×10^{-15}. This is well within the 1σ uncertainties of the two standards. (T. Parker and J. Levine)

■ **A Transportable Cesium Fountain.** A small, transportable cesium-fountain standard has recently been constructed and demonstrated in a preliminary way by T. Heavner and S. Jefferts. The objective of this work is a transfer standard of very high reproducibility that can be used to compare widely separated primary standards. As primary standards have increased in accuracy, the noise (and possibly biases) in satellite comparison methods have risen in importance, and it is now essential that these be evaluated using a transportable artifact.

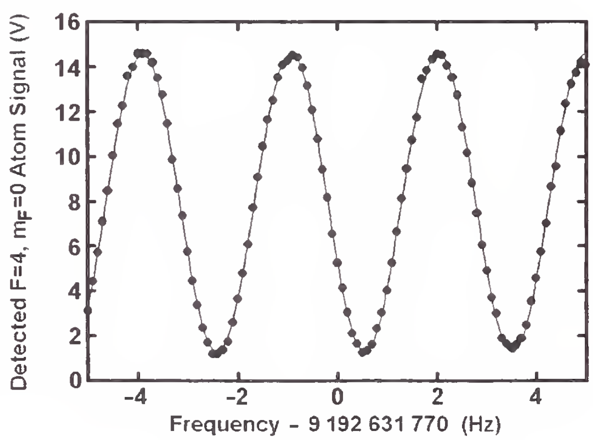


Figure 1. Central portion of the Ramsey pattern for the small cesium standard. The frequency offset is due to the relatively large C field. The solid line is a fit to a sine wave.

The small toss height (30 cm) and large aperture of this small standard assure very high signal-to-noise performance, assuring that measurement time is limited solely by the primary standard, not the transportable device. Figure 1 shows the central portion of the Ramsey fringes from this device, which at this time is not fully shielded magnetically. Additional improvements will be made during the next six months before serious efforts are made to study the size and stability of systematic effects.

The development of this small standard will also have impact on the next NIST primary frequency standard, since some of the systems developed will be useful in that development. These systems include a laser package that delivers cooling, state-preparation, and state-detection radiations to the standard through polarization-maintaining optical fibers; and collimators on the source chamber designed to assure efficient trapping of larger numbers of atoms. (T. Heavner)

■ **Phase-Modulation Servos for Atomic Clocks.** S. Jefferts and F. Walls of the Physics Laboratory in Boulder, in collaboration with Bill Klipstein and John Dick of the Jet Propulsion Laboratory (JPL), have developed an improved modulation method for laser-cooled atomic clocks, providing for a high level of immunity to vibrations and substantial reduction of a number of systematic frequency shifts that can affect these clocks.

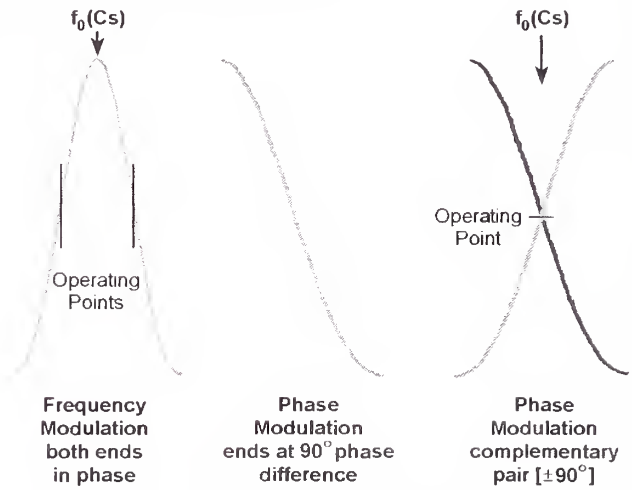


Figure 2. Schematic representation of the difference between frequency modulation and phase modulation. As can be seen, the operating points for frequency modulation are the steepest points on the resonance, whereas phase modulation leads to operation on the peak of the resonance, where perturbations have the least effect.

The concept involves phase modulation of the interrogating microwave field rather than the traditional frequency modulation used in most atomic clocks. In this new scheme, graphically shown in fig. 2, the phase of the microwave field in the first portion of the Ramsey cavity is fixed and the phase in the second Ramsey region is varied alternately between +90° (relative to the phase in first region) and -90°. The advantage of the method is that the frequency of the microwave field can be kept continuously on the center of the resonance, rather than being stepped from one side of the resonance to the other as is done using frequency modulation. At the peak of the resonance the clock is substantially less sensitive to vibration and to systematic effects such as line pulling and cavity pulling than it is when the system resides most of the time on the steepest portion of the resonance curve.

The concept was initially developed to take care of the vibration sensitivity of the laser-cooled clock on the Primary Atomic Reference Clock in Space (PARCS). In this collaborative program, involving NIST, JPL, the University of Colorado and the Harvard-Smithsonian Center for Astrophysics, a laser-cooled cesium clock will be put aboard the International Space Station (ISS) in 2005 to perform certain tests on gravitational theory and to improve upon the realization of the second. The modulation concept was tested on the NIST cesium-fountain clock, NIST-F1, and found to work so well that it has become the preferred mode of operation. It has also been picked up by others and is being used on other fountain clocks around the world. (S. Jefferts).

■ **PARCS Advances Through NASA Reviews.** The NIST-led program entitled Primary Atomic Reference Clock in Space (PARCS) successfully completed its second NASA review, the Requirements Definition Review, in December 2000. This review, which included both a science panel and an engineering panel, considered both the scientific merits of the mission and the technical feasibility of the proposed experiments. This was the final review of the science involved. Subsequent reviews will focus on the engineering development of the flight systems.

This NASA-funded mission, which is a collaboration among NIST, the Jet Propulsion Laboratory, the University of Colorado, the Harvard-Smithsonian Center for Astrophysics, and the Politecnico di Torino, is currently scheduled to fly in 2005. The objectives are to test certain aspects of relativity theory, to improve upon the realization of the second, to study the performance of GPS clocks, and to study the dynamics of atoms in microgravity.

In its report to NASA, the Review Panel recommended that "...the PARCS project should proceed with all possible speed and deliberation toward the Preliminary Design Review, ..." The Panel also concluded that, "...based on all material presented to date, the experiments should fly and can succeed." A complete preliminary design of the system will be considered in the next review, which is scheduled for late summer 2002. (D. Sullivan)

■ **Chip-Scale Atomic Clocks.** Following their development last year of a very compact cesium frequency standard, J. Kitching and L. Hollberg have been working on concepts that might someday allow atomic standards to be reduced to chip scale. A particular focus of their studies has been the use of dark states, which provide the means for interrogation of a microwave resonance without need for a physical microwave cavity. In this scheme, the traditional clock transition is probed through a microwave modulation imposed on a laser signal tuned to an optical transition. Some effort has been made to develop at least first-order models of the scaling laws appropriate to reduction to this scale. For example, fig. 3 shows the scaling of the atomic Q factor with size for three types of gas cell.

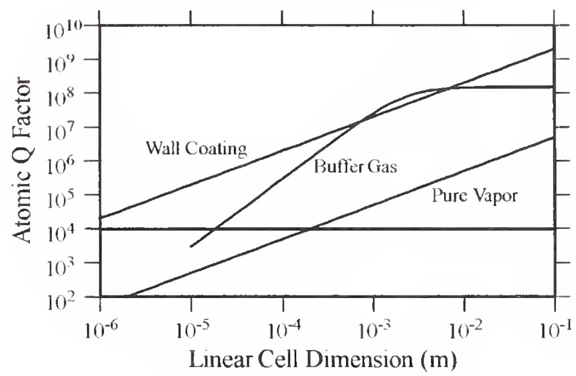


Figure 3. First-order scaling laws for atomic clocks based on gas cells. The model is based on cubical cells (all dimensions equal). The horizontal line is the Q of a typical mechanical microresonator of the sort that might be used in a chip-scale clock. For very small gas cells, it is clear that wall-coated cells will be the best choice.

While clock performance would clearly be degraded by reductions in size and power requirements, there are many applications where such clocks might be extremely useful. For example, electronic instrumentation (such as frequency counters), where an accurate time base is needed, would benefit, since an atomic standard would bring intrinsic accuracy to the instrument. Furthermore, small and inexpensive devices of this sort would find application in GPS receivers, where they would provide the accuracy needed to achieve more rapid navigation solutions, and in telecommunications systems, where there is a need for a very large number of clocks with performances better than are provided by quartz oscillators.

The NIST work is very timely, since the Defense Advanced Research Projects Agency (DARPA) has just initiated a call for proposals aimed at developing such a clock, and NIST is thus well positioned to assist DARPA as it engages industry in this development project. (L. Hollberg)

■ **Heating of Trapped Ions from the Quantum Ground State.** Excess heating, which has been limiting correlation times in quantum-logic experiments, has recently been reduced substantially through shielding of trap electrodes from beryllium deposition on the electrodes. This shielding was implemented following heating studies, wherein Q. Turchette, D. Kielpinski, B. King, D. Meekhof, M. Rowe, C. Sackett, W. Itano, C. Monroe, D. Wineland, D. Leibfried, C. Myatt, and C. Woods showed that the scaling of the heating with trap size was inconsistent with the source being Johnson noise in external circuits, and consistent with fluctuating patch-potential fields on the trap electrodes. If patch effects could explain the heating, then it was clearly logical to do something about the state of the electrode surfaces. The first step was to shield the electrodes by masking the neutral beryllium atom source, preventing deposition of beryllium on the electrode surfaces.

The observed reduction in heating was large, decreasing the level seen in previous work by a factor of 200-300. While this will ultimately enable increasing the number of quantum-logic operations by this same factor, Raman laser intensity noise and noise caused by fluctuations in the background magnetic field must be reduced before this benefit can be realized. (D. Wineland).

■ **Entangled, Spin-Squeezed States.** By applying coherent laser beams to trapped ions, PL staff in Boulder have generated quantum-mechanically-entangled, "spin-squeezed states and, for the first time, shown that such states can be used to increase measurement precision beyond that which is possible without the use of entanglement. V. Meyer, M. Rowe, D. Kielpinski, C. Sackett, W. Itano, C. Monroe, and D. Wineland have recently reported the results of these studies in the Physical Review Letters. As a demonstration, they produced spin-squeezed states of two beryllium atomic ions and showed that when the spins are rotated in a magnetic field, the uncertainty in determining the rotation angle is smaller than can possibly be obtained if the atoms are not entangled. The spin-squeezing result is shown in fig. 4. Such techniques are an integral part of the emerging fields of quantum logic and quantum information, but can also be used to improve sensitivity in spectroscopy or reduce noise in atomic clocks.

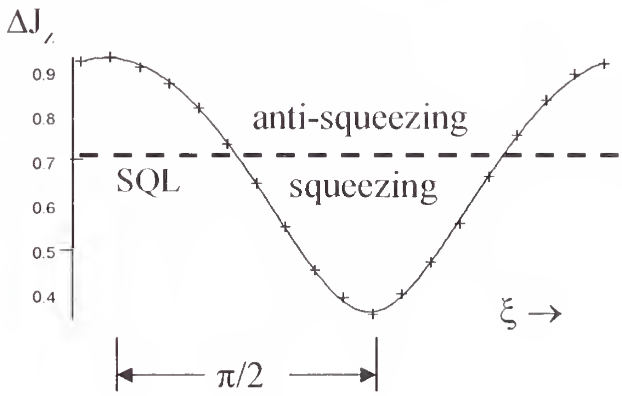


Figure 4. On the vertical scale we show the measured fluctuations of the spin measured in a direction perpendicular to the direction of the net spin vector. For an unsqueezed "coherent" spin state the fluctuations are independent of the azimuthal angle ξ around the direction of the spin (the "standard quantum limit," SQL). For a squeezed entangled state these fluctuations are reduced for certain angles. This "spin-squeezing" gives rise to increased sensitivity in spectroscopy.

Although spectroscopic precision can always be improved by increasing the number of atoms (without the need for entanglement), in atomic clocks based on ions for example, the quest for accuracy requires the use of only a small number of ions. With a potential uncertainty of 1 part in 10^{18}, these techniques should actually find application in optical ion clocks. (D. Wineland)

■ **Coherence Between Nodes of a Dual Multiplexed Trap.** In order to build a multiplexed quantum computer based on trapped ions, coherence must be maintained as ion qubits are transferred between traps. This was recently demonstrated by M. Rowe, V. Meyer, A. Ben-Kish, J. Britton, B. DeMarco, J. Hughes, W. Itano, D. Leibfried, and D. Wineland in a kind of Ramsey experiment between two traps. In this three-step experiment on a single ion (illustrated in fig. 5), a $\pi/2$ pulse is first applied to the ion as it sits in trap 1, and the ion is then shuttled to trap 2 where it is subjected to a π pulse. The ion is then shuttled back to trap 1 where the final $\pi/2$ pulse is applied to it. This sequence of pulses is similar to that typically applied to an ion in a single trap to achieve Ramsey interrogation, but here the ion has been shuttled between traps during the experiment to determine whether coherence is lost in the process of shuttling. The 3-pulse ("spin-echo") technique is relatively immune to slow drifts in magnetic field over the averaging time of the experiment, but is sensitive to the coherence between traps 1 and 2. The Ramsey-fringe contrast in the figure demonstrates that coherence. (D. Wineland)

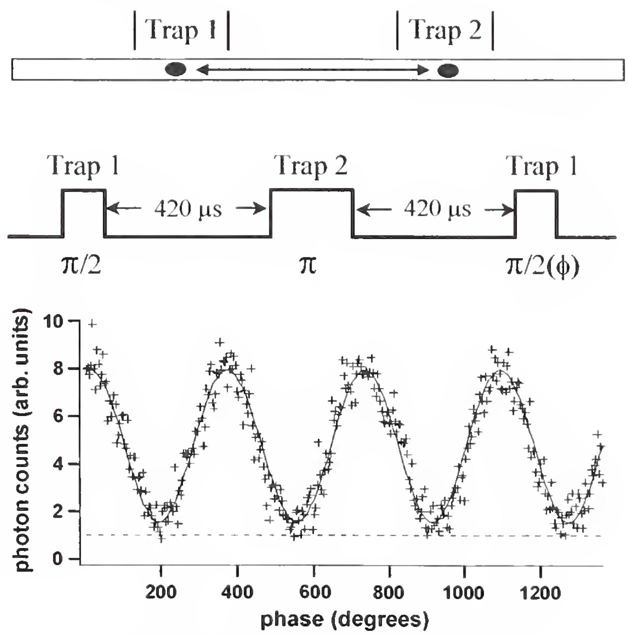


Figure 5. Illustration of Ramsey interrogation in a dual multiplexed ion trap. The time sequence of pulses applied to the single ion in the two different traps is shown in the middle portion of the figure, and the resulting Ramsey fringes are seen at the bottom.

■ **Quenched Narrow-Line Cooling of Calcium.** C. Oates and L. Hollberg, along with A. Curtis of the University of Colorado have recently achieved sub-Doppler cooling of ^{40}Ca to near the recoil limit using a quenched narrow-line laser-cooling method. Since the Doppler limit is large, typically of the order of 1 mK, for alkaline-earth-metal atoms, the uncertainty of optical standards based on these atoms has been limited. In fact, the best frequency measurement (± 26 Hz) of the 657 nm (456 THz) transition in calcium, which was made recently at NIST, was principally limited by residual atomic velocity.

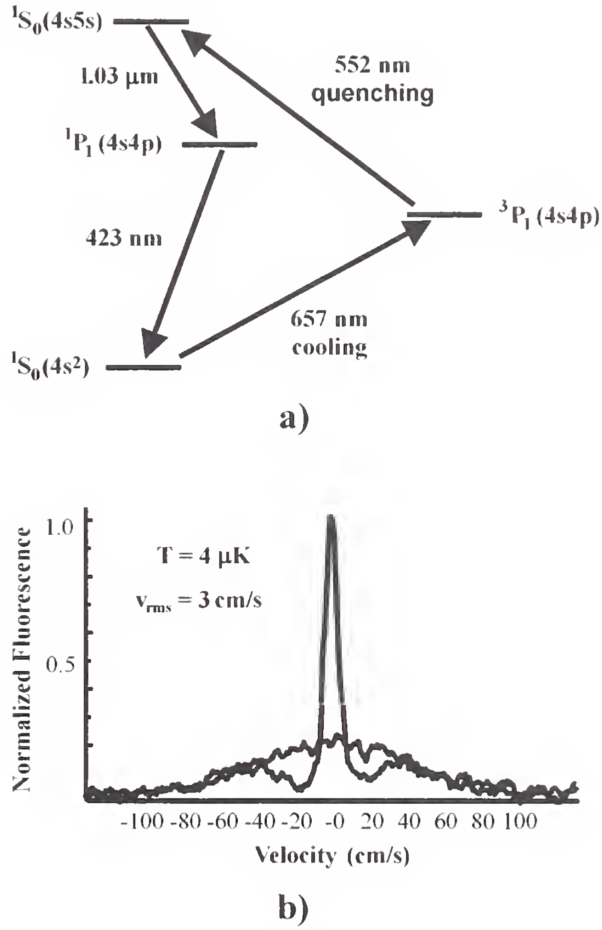


Figure 6. a) Energy level diagram for calcium showing levels used in the narrow-line quenched-cooling technique. b) Velocity distribution of atoms before and after quenched cooling. The broad curve is near the Doppler-cooling limit and the narrowed one is near the recoil limit.

The cooling process is illustrated in fig. 6. Because of the long lifetime of the $^3P_1$ state, the width and shape of the velocity group excited from the $^1S_0$ state to the $^3P_1$ state can be readily controlled. In a step wise fashion, a 657 nm laser is tuned slightly red of the transition to transfer a velocity group of atoms to lower velocity through a one photon recoil to the $^3P_1$ state, and a subsequent pulse of 553 nm (propagating in the same direction) light moves the atoms to the $^1S_0$ (4s5s) while giving them a second kick toward zero velocity. These atoms return to the ground state through the two decays (and their random recoils) shown in the figure. This process is then repeated with pulses from the opposite direction, so that a second velocity group on the opposite side of the distribution is moved toward zero velocity. This process is repeated many times, driving all atoms toward zero velocity, where they have a much smaller probability of being pumped away (since the pump laser is preferentially pumping higher velocity atoms).

Using this method, calcium atoms were cooled in one dimension to as low as 4 μK. Further improvements on this cooling will be made, and it will be extended to three dimensions. The objective is to improve upon the accuracy of the calcium optical standard, which is the only optical standard for which high-accuracy international comparisons have been made. The best comparison to date is between NIST and PTB, where a difference of 30 Hz was measured. This is well within the uncertainties of the individual measurements. (C. Oates)

■ **Diode Lasers Locked to Optical Cavities.** R. Fox and L. Hollberg have succeeded in controlling the fluctuations of diode lasers with respect to the resonances of optical cavities, allowing them to build systems that will be useful for analytical applications and length measurement.

In their experiments, they demonstrated locking to narrow modes (~5 kHz) of very high-finesse optical cavities with a servo-control bandwidth of 3 MHz, followed by un-locking and re-locking to the same mode at rates as high as 2 kHz. This capability is important to cavity ring-down spectroscopy, an analytical technique used by many laboratories to measure extremely small (trace) amounts of certain atoms and molecules. Usually, this work is accomplished using poorly controlled pulsed laser sources. Better sensitivity can be obtained using continuous-wave lasers, but to achieve higher sensitivity it is necessary to frequency lock the laser to the ring-down cavity as has been done here.

A second application of this work is to swept-wavelength laser interferometers used for length measurement. Well-controlled diode lasers will be able to measure 10-20 meter path lengths with micrometer uncertainty if the laser can be swept over a precisely known wavelength interval, for instance by moving the frequency of the laser precisely between two different modes of a stable optical cavity. With the systems developed here, it should be possible to lock the laser to a high-finesse laser mode, un-lock the laser, change the laser wavelength by several nanometers, and then re-lock to another mode. (R. Fox)

■ **Standards for Optical Communication.** In collaboration with S. Gilbert, N. Newbury, and K. Corwin of EEEL, L. Hollberg and S. Diddams of the Division have initiated development of a mode-locked femtosecond laser that will provide a comb of frequencies overlaying the important optical-fiber communication bands. The objective of the project, which is supported by ATP, is to establish extremely accurate measurements in support of wave-division multiplexing (WDM), which is used extensively in optical telecommunications systems. Because these optical systems are moving to higher data rates through closer channel spacing, accurate measurements of channel location and spacing are becoming increasingly important.

The new laser system, which uses an optical cavity with dispersion compensation and a crystal of Cr:Forsterite, has been designed and all specialized components for its construction have now arrived. The reference frequency for these measurements will be the 657 nm line in calcium, since this has been extremely well measured by several laboratories over the last few years. A division by two of the calcium line produces a line in the vicinity of 1.3 μm, right within the region of interest for measurements supporting WDM. This ATP-supported project also involves the application of these new combs to length metrology. Jack Stone of MEL is collaborating with the Time and Frequency Division on this part of the program. (S. Diddams)

■ **Further Growth and Improvements of the Network Time Service.** Use of the NIST Network Time Service (NTS) continues to grow at a monthly compounded rate of about 8.5%, with current usage at over 200 M hits per day. To meet this growing use, J. Levine has installed two additional servers.

He has also modified the code by sending special packets that allow users to obtain either UTC or TAI. This addition of TAI was made in response to requests from users who want a time scale that is absolutely continuous and free of leap seconds. In order to deal with new operating systems he has written new client software for Linux and Windows 2000/ME/XP.

Work also continues with three companies that are developing special-purpose hardware and software to provide secure time services to financial markets, where concerns for the legal authenticity for time/date stamps is driven by the potential for expensive mistakes, or even fraud. (J. Levine)

■ **Microwave Synthesizers for Advanced Frequency Standards.** Low-phase-noise synthesizers play a critical role in the performance of primary frequency standards, so the Division has been working to improve the reliability and performance of these devices to support rapid advances in these standards. C. Nelson and D. Howe of the Division, along with guest researchers F. Garcia and A. Hati, have recently made substantial improvements that are important, not only for fountain standards, but also for other frequency standards such as the laser-cooled space clock for the PARCS mission. Of particular significance to this latter project is the complete re-engineering of the system to operate on the lower DC voltages that are used on the space station. However, the most important improvement has been the reduction in sensitivity to temperature variations. The synthesizers now exhibit a temperature coefficient on the order of 0.1 ps/K. It is important to minimize this coefficient, because this has an impact on phase changes that occur during dead time in the standards.

NIST leadership in this area is highlighted by the fact that most new standards in the world are or will be using the NIST synthesizer. In fact, there are very few programs that are building their own synthesizers. NIST has now completed and delivered ten synthesizers to other programs, primarily other primary standards laboratories, and four more are under construction. Because the operational mode and requirements of the various standards are different, some custom design changes have been made with almost every one of these synthesizers. (C. Nelson)

■ **Calibration System for Phase and Amplitude Noise at 100 GHz.** D. Howe and F. Walls have developed a system for calibrating the level of phase-modulation (PM) noise and amplitude-modulation (AM) noise at 100 GHz in oscillators, amplifiers, and other components. At this time the two key applications of the system are to the clocking of high-speed digital processors and evaluation of the performance of broadband telecommunications signals.

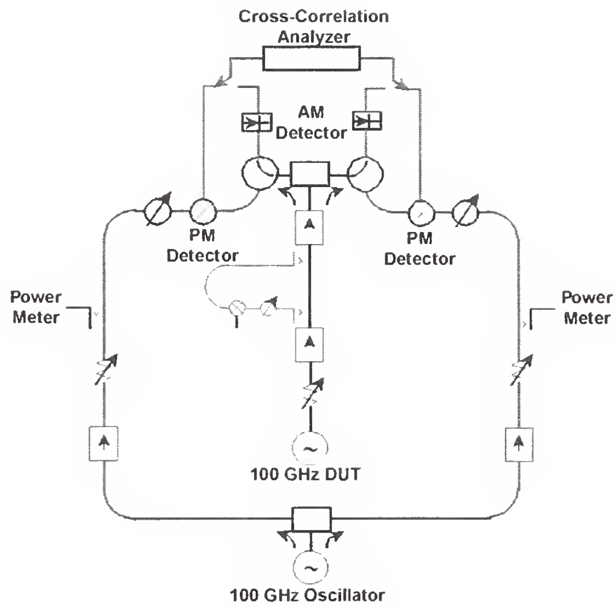


Figure 7. Simplified block diagram of the system used for measuring PM and AM noise at 100 GHz. The DUT (device under test) is an oscillator or some other component such as an amplifier. In the latter case the component is fed a signal from the main 100 GHz reference oscillator. The dual-loop configuration, along with the cross-correlation analyzer, provides the means for canceling out the noise contributions from many of the elements (e.g., mixers and detectors) in the measurement circuit.

The system, shown schematically in fig. 7, relies for reference on a cavity-stabilized Gunn oscillator that serves as a low-noise reference signal. The oscillator is coupled and locked to an ultra-low-noise sapphire loaded cavity oscillator (SLCO) through several regenerative frequency dividers, and the broadband noise of the system is then limited by the mixer and divider noise. Measurement of phase or amplitude noise at 100 GHz is by two nearly identical phase-locked loops whose phase deviations are analyzed simultaneously using a cross-correlation spectrum analyzer. Because most of the noise generated in the components (mixers and detectors) in one channel is independent of the noise generated in the same components in the other channel, it does not show up in the correlation measurement. (D. Howe)

■ **Repair of WWVB Antenna System.** On February 28 of this year, a 400 foot tower of the 60 kHz antenna system for WWVB partially collapsed, resulting in a reduction of broadcast power by nearly a factor of two. Since there are a very large number of receivers, clocks, and watches that are controlled by this broadcast service, there was an immediate reaction from those located substantial distances from the transmitter (Florida, New Hampshire, etc.). The signal-to-noise ratio in these areas was degraded to the point where reception was marginal. In response to this mishap, the NIST Acting Director directed the expenditure of special funds to bring the station back to full power as quickly as possible. This turned out to be a complicated process, however, full power was restored on June 15.

The WWVB broadcasts emanate from a pair of transmitters that are operated in phase and radiate their respective signals from two closely spaced antenna systems. This design allows for short-term maintenance of one system or the other without shutting down the broadcasts and provides some longer-term reliability. In order to minimize the impact on users during the repairs, the radiating element for the damaged antenna was partially raised providing a total power output of 38 kW, substantially below the normal operating power of 50 kW, but better than the output of 28 kW from a single transmitter system.

The cause of the antenna damage was structural failure in a metal component in one of the insulator assemblies that isolate the antenna guy wires from ground. This failure is being studied by the Materials Reliability Division of the Materials Science and Engineering Laboratory. Their recommendation will form the basis for replacement of similar insulator assemblies used on all the guy wires. Repair of the antenna, led by M. Deutch and J. Lowe of the division, involved custom fabrication of the upper third of the tower, disassembly of the tower, and then reassembly with the replacement sections. Since there are only two cranes in Colorado capable of handling components at this height, scheduling of the repair was difficult. Furthermore, to prevent damage to underground antenna components in the soft soil surrounding the antennas, a short section of roadbed had to be laid to support the great weight of this crane. (J. Lowe).

■ **WWVH Antennas.** As part of a program to eventually replace all eleven antenna masts at WWVH in Kauai, last year the Division replaced two of the masts with fiberglass whip antennas (see fig. 8), and has initiated replacement of two additional masts. D. Okayama and D. Patterson at the station in Kauai and J Lowe and W. Hanson in Boulder are leading efforts on this project. Despite vigorous maintenance efforts, these 30 year old antenna masts have suffered serious corrosion in the salt-water environment, and, because they are becoming weakened structurally, they pose risks to those maintaining them. The first two replacements were of broadband antennas used as backups for the main antennas operating at 5 MHz, 10 MHz, and 15 MHz. The replacements this year is for the primary antenna and backup antenna used for broadcasts at 2.5 MHz. These are substantially taller antennas. As noted previously, the capital investment in these new antennas will be recovered, in the form of reduced maintenance costs, in about 7 years. (J. Lowe).

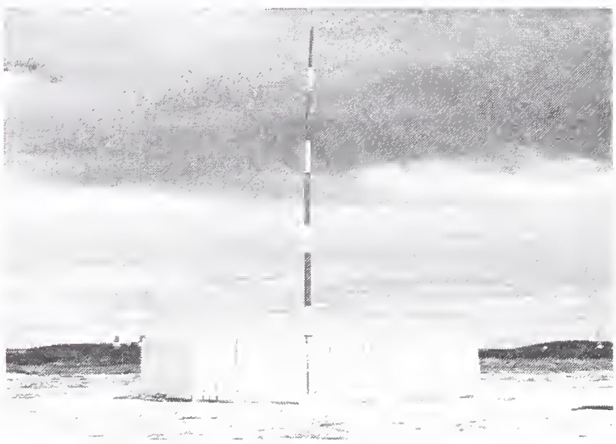


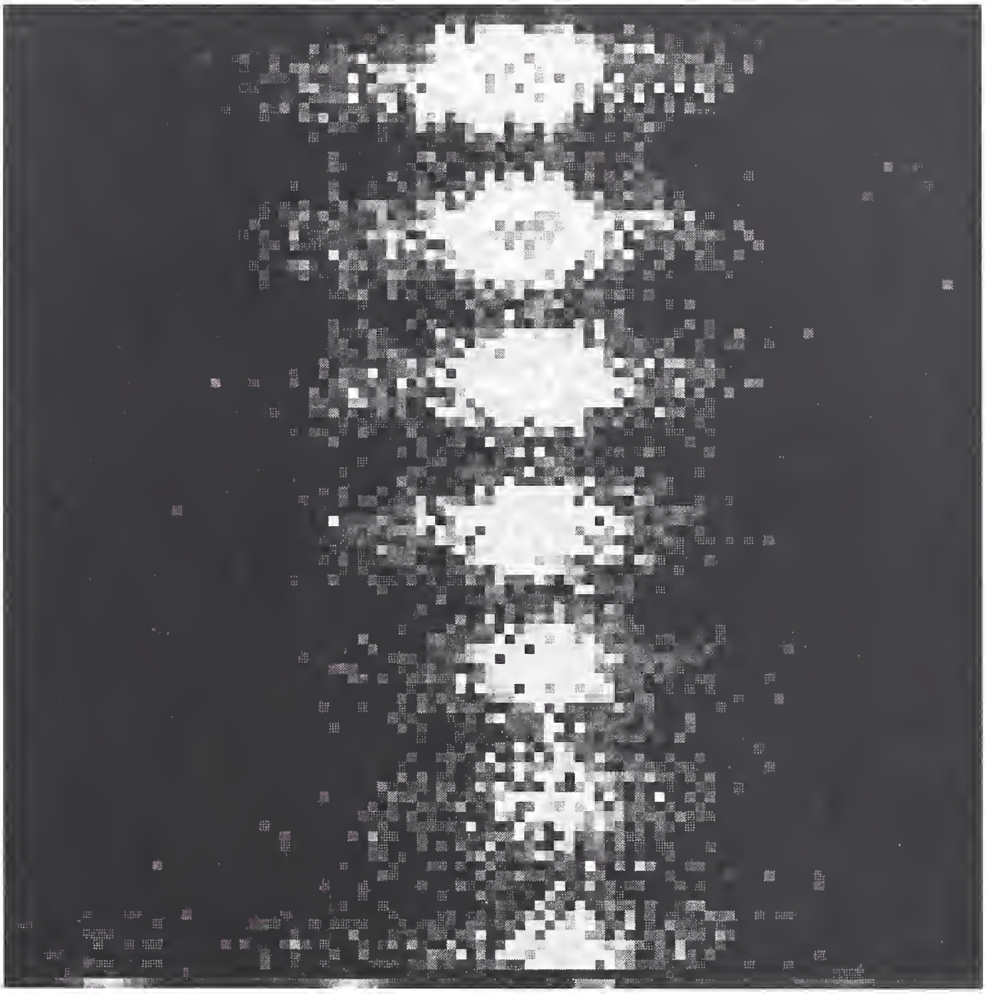
Figure 8. New whip antenna at WWVH on Kauai. Conventional antennas are seen in the background. The fencing is a safety measure, preventing personnel access to the high voltages on the antenna system.

■ **Time-and-Frequency Users Survey.** A customer survey covering most Division dissemination services was developed this year by J. Lowe and J. Heidecker of the Division, and all customer survey input has now been received. More than 18,000 responses to the survey have been received, a very significant increase over the 7000 responses that were received during the last survey in 1987. The objectives of the survey are to gauge customer use of the various services, determine whether there are any problems with how the services are provided, and elicit suggestions on user requirements that could lead to modifications of existing services or the development of new services.

The focus of the survey is on the NIST radio broadcasts (WWV/WWVH/WWVB), the telephone time service (Automated Computer Time Service), and Internet time services (including the Network Time Service), the active Internet clock (time.gov), and the informational content of the Division's web pages. The results, which could take as long as 6 months to tabulate and analyze, will guide the Division in both its near-term and long-term planning for the future of its services. (J. Lowe)

■ **Time-and-Frequency Publication Data Base.** M. Lombardi and A. Novick, with support from G. Bennett have made a large number of improvements in the Division's web site, with the key improvement in the area of Division publications. The Division's database of more than 1500 publications is now on the web, and for more than 1/3 of these, including most recent ones, the full paper is available on line. A plan is now in place to systematically scan the older publications and make them accessible, so that all papers are eventually available on line. This will reduce staff time associated with sending out reprints, and will provide better support to Division researchers, who must have ready access to all Division publications. The Division web site, excluding the time services receives by far the largest number of external hits, with over 300,000 page views per month. (M. Lombardi) ❑

QUANTUM PHYSICS DIVISION



Overleaf

Ultracold, fermionic potassium atoms released from an optical trap. In this image we see atoms in seven different spin states, separated for imaging by a spatially inhomogeneous magnetic field. By trapping atoms in multiple spin states we can explore interaction effects, such as the possibility of Cooper pairing, in the Fermi gas.

QUANTUM PHYSICS DIVISION

OVERVIEW

Through the Quantum Physics Division, NIST participates in JILA, a cooperative Institute between NIST and the University of Colorado (CU). The Division conducts long-term, cutting edge research in quantum physics and related areas in support of the Nation's science and technology.

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

The governing body of JILA, its "Fellows," consists of 24 permanent senior scientists who set policy, subject to review by the Director of NIST and the President of CU. A biennially elected Chair, assisted by the NIST Division Chief acting as an Associate Chair, together with an executive committee are responsible for operating the Institute within the policies set out by the Fellows. Of the present 24 active Fellows, 14 are tenured State of Colorado faculty members – six in the Department of Physics, two in Chemistry, and six in Astrophysical and Planetary Sciences – and 10 are NIST employees – nine in the Quantum Physics Division and one in the Time and Frequency Division. Currently, one NIST scientist and one CU scientist 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 their respective employer, NIST and the Physics Laboratory Director in some cases, CU and the pertinent academic department in the others. During 2001, approximately 100 graduate students and postdoctorals were supervised by NIST scientists and approximately 40 staff were associated with NIST activities.

JILA was formed in the early 1960's in response to serious gaps in our basic understanding of the physics of gaseous atmospheres (terrestrial, planetary, solar, and stellar). Subsequently JILA has evolved to respond to new scientific opportunities, changing national needs, and 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 well as biophysics. As NIST's mission has expanded to include support for industry, the criteria used by division scientists to direct their research programs have also been modified.

In pursuit of the NIST mission, the Division:

- develops the laser as a precise measurement tool;
- determines fundamental constants and tests the fundamental postulates of physics;
- exploits Bose-Einstein condensation as well as quantum degenerate Fermi gases for metrology and low temperature physics;
- investigates new ways to direct and control atoms and molecules;
- characterizes chemical processes and their interactions with nanostructures;
- studies the interaction of ultrashort light pulses with matter; and
- is implementing a new program in biophysics.

PROGRAM DIRECTIONS

■ **Degenerate Bose-Einstein and Fermi-Dirac Gases.** The Division remains committed to exploring and exploiting the ultimate limits in low-temperature gases. The two basic species of atoms, fermions and bosons, behave very differently at ultra-low temperatures. Each offers opportunities in precision sensing and metrology, and in each case the effects of quantum mechanics, ordinarily masked by random thermal behavior, are dominant.

■ **Laser Research.** In laser research, various schemes are explored for stabilizing lasers and also for using them as frequency standards. Recent work addresses the creation, utilization; and study of "ultrafast" laser pulses, which can be applied to investigations of semiconductor materials both to produce and control wave packets and to study nonlinear optical wave interactions. The evanescent wave property of light has been exploited to "guide" atoms through hollow fibers (i.e., to prevent them from touching the sides). Finally, the Division has a rapidly developing research thrust in ultrafast phase control and frequency measurements, which are applied to control both atom and molecule dynamics, as well as to access wholly new methods of frequency and length standards.

■ **Fundamental Constants and Tests of Fundamental Postulates.** There is considerable overlap with our laser research mentioned above and our work to develop lasers as optical frequency standards by producing different and better stabilized lasers. In addition, a new determination of G, the Newtonian constant of gravitation, is underway. Work is also progressing on a new absolute instrument that will make the transfer standard g, the acceleration gravity, more accessible for field measurements by the external research community for whom it provides a valuable indicator of vertical height changes (e.g., in observing post glacial rebound) as well as subsurface mass movements (e.g., in volcanology).

■ **Nanostructure Development**. Various forms of surface microscopies and optical probe techniques are important subjects for film thickness control and the investigations of nanostructures. Initially begun as a competence project in near field microscopy, challenges are addressed for ultrafast time contrast with high spatial resolution; these efforts have met with preliminary success. Deposition of films with precise layer thickness and composition are studied by laser detection methods and ion scattering probes.

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

■ **Biophysics.** The Division has initiated a program in biophysics – a rapidly expanding area of National and NIST interest.

MAJOR TECHNICAL HIGHLIGHTS

■ **Precision Spectroscopy in Cold, Dense, Trapped Atomic Samples.** The technology developed for creating Bose-Einstein condensation has been used to create very dense and very cold samples of Rubidium atoms for studies of systematic effects in microwave spectroscopy. The densities of these samples are five orders of magnitude higher than in cold-atom fountain clocks, and the temperatures are within 40% of the transition temperature. The microwave linewidths are comparable to those in modern fountain clocks, but near the onset of quantum collective behavior the sources of systematic error associated are much larger. At these very high densities, atom-atom interaction terms are very large. Mean-field as well as exotic collective frequency shifts also become very large and are typically resolvable in just a few seconds of integration time. Quantitative and qualitative understanding of these errors in this high-density regime will allow very precise corrections to be applied in the low-density, precision regime of next-generation atomic clocks. (E.A. Cornell)

■ **Condensate Interferometry.** A new apparatus capable of combining two atom-optic technologies -- Bose-Einstein condensation and lithographically patterned atomic wave-guides -- is nearing completion. Condensation has already been observed in the new machine and the wire-guiding technology is being integrated into the apparatus. The combined machine will be capable of measuring gravity gradients interferometrically, with applications to remote sensing, geodetics, and navigation. (E.A. Cornell)

■ **Exploding Solitons.** Recent theoretical results suggest that soliton instabilities can exist in the presence of dissipation (gain and/or loss). These instabilities can result in the temporal length of the soliton suddenly increasing followed by the soliton returning to its steady state (an "explosion"). Mode-locked lasers make an excellent test bed for soliton dynamics (in the dispersion-managed regime) because their output provides a sampling of the pulse after each round trip. Because capturing the actual temporal behavior at a high enough rate is impossible, we monitor the spectrum. Indeed, events are observed where the spectrum abruptly shift and narrow before returning to the steady state (see fig. 1). Depending on the dispersion, either single explosions or bursts of explosions occur. This work may have significant impact on long distance telecommunications where dispersion-managed solitons are a candidate format. The presence of such instabilities must be taken into account to avoid errors. (S.T. Cundiff)

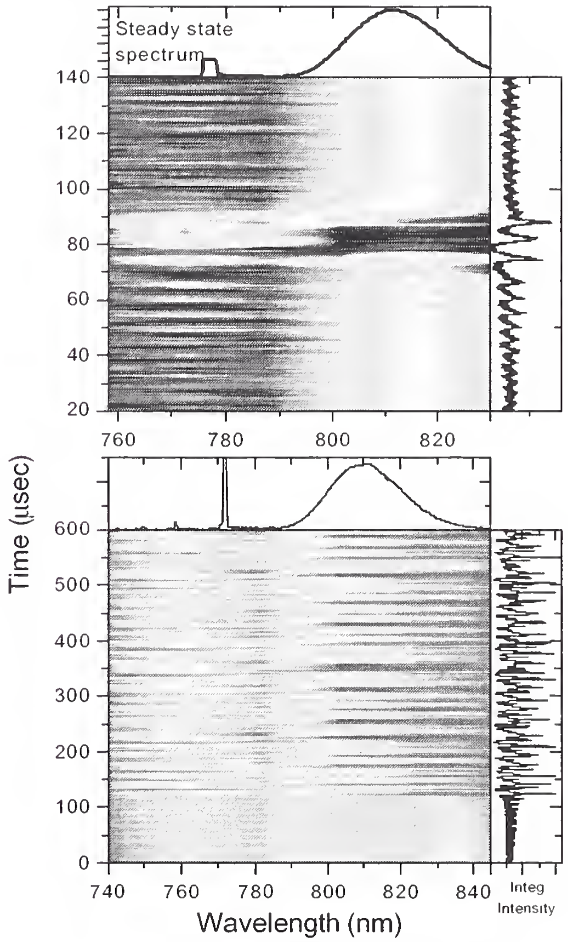


Figure 1. Typical data showing soliton explosions. In the upper panel the dispersion is adjusted to yield solitary explosions, while in the lower it is adjusted to yield bursts of explosions. The resolution and position of spectral channels has been optimized in the lower panel.

■ **Coherent Response of Semiconductors.** The coherent response of semiconductors is very sensitive to many-body interactions among the optically excited electrons and holes. A theoretical understanding of this coherent response has been developed over the last decade. Some approaches have developed a microscopic theory starting from the electron-hole Hamiltionian, while others have taken a phenomenological approach that is more appealing to one's physical intuition. We have discovered a new term in the phenomenological theories that is due to excitation induced shifts (EIS). Transient four-wave-mixing (TFWM) is the most common tool for probing the coherent response [see fig. 2(b).] We observe that the spectrum of the TFWM signal displays a split peak [see fig. 2 (c and d).]

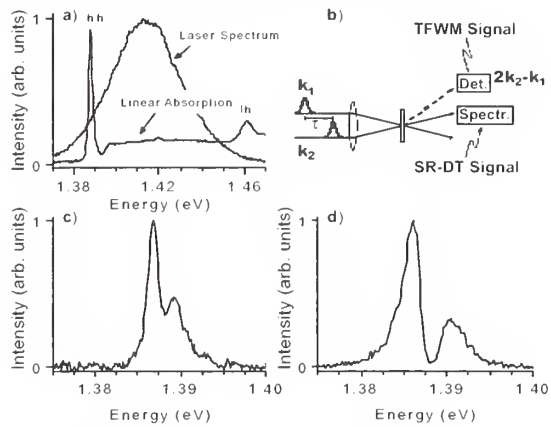


Figure 2. (a) Linear absorption and laser spectrum. Experimental setup (b) shows the two-pulse configuration for TFWM and DT in transmission. Typical TFWM spectrum, in transmission (c) and in reflection (d), both for τ=0 delay.

Our phenomenological calculations only reproduce a split peak if EIS is included in addition to the well known phenomena of excitation induced dephasing and local fields (see fig. 3). To the best of our knowledge, the role of EIS has not been pointed out previously. The understanding of how many-body phenomena in semiconductors affect their interaction with light is crucial for developing a theoretical description of light-emitting diodes and laser diodes. (S.T. Cundiff)

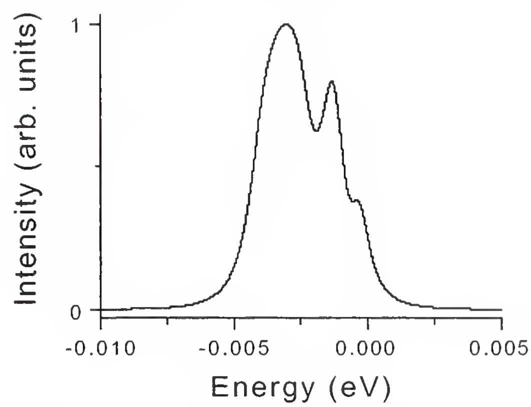


Figure 3. Numerical calculation of a TFWM spectrum using the MOBE, with both EID and EIS present.

■ **Phase Stabilization of Modelocked Lasers.** Stabilization of the carrier-envelope phase of modelocked lasers has recently resulted in a revolution in optical frequency metrology and is the enabling technology for the recent demonstration of optical atomic clocks in both the Time and Frequency Division and the Quantum Physics Division. We are currently focusing on understanding phase noise processes that introduce uncertainties into the results. One area of concern is the microstructure fiber used to broaden the pulse spectra. Because this broadening is a highly nonlinear process, it might be expected that small amplitude fluctuations in the laser power would be converted to significant phase fluctuations. As shown in fig. 4, we have measured this conversion factor and determined that it is insignificant. This is because it is the differential phase that matters, the phase between the pulse envelope and its carrier. Because the amplitude fluctuations have a common effect on both the pulse envelope and its carrier, the impact on the experiments is minimal. We are now turning to measuring the power spectrum of the frequency noise emitted by the laser, this which will allow us to determine the coherence time among the pulses in the train. (S.T. Cundiff)

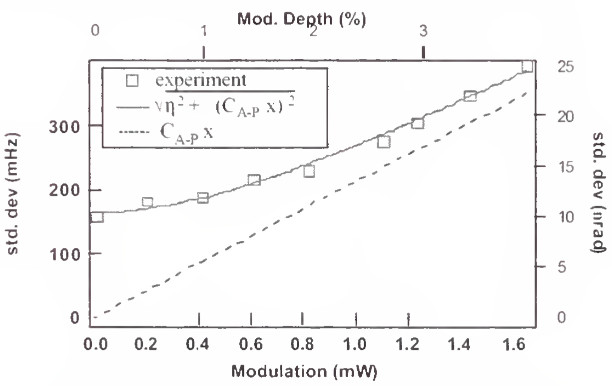


Figure 4. Measurement of the change in carrier-envelope phase (right axis) as function of amplitude modulation of the laser. A known modulation of variable amplitude is imposed on the laser to allow the conversion from amplitude to phase to be determined. The background phase noise is apparent at zero modulation. This adds in quadrature to the generated phase modulation to produce the curved line.

■ **Multiple Input AND Gate by Molecular Wave Packets.** An AND gate represents a useful mathematical algorithm for computation: if all the inputs are 1, the output is 1; all other combinations of inputs give an output of 0. Using quantum interferences resulting from a coherent superposition of rovibrational molecular states in an ultrafast pump-probe experiment in molecular lithium dimers, a six-input AND has been demonstrated. The input values (0's or 1's) are imprinted into the phases of the eigenstates by a shaped femtosecond pulse. The computation is carried out by the quantum beat interferences during the field-free time evolution. The resultant output is probed at a specified delay time by ionization of the wave packet to determine the amplitude of the recurrences. A set of phases that obtains a global maximum output at a specific time delay is predetermined and defined as an output of 1; any other amplitude value, caused by different phases, is an output of 0. For the six-input AND gate studied here, a >99% success probability is achieved with a typical signal-to-noise ratio of 10. This can be improved considerably by additional signal averaging times or extended to hundreds of inputs. The results have applicability to problems such as determining whether a graph, consisting of points and edges connecting the points, has any isolated vertices. (S.R. Leone)

■ **Femtosecond Soft X-Ray Pump-Probe Dynamics.** Ultraviolet photoelectron spectroscopy and x-ray photoelectron spectroscopy are important methods used to study the structure and energetics of neutral molecules, radicals, and semiconductor surface processes such as etching. Thus far it has not been experimentally feasible to study ultrafast processes of neutral molecules or materials surfaces with direct ultraviolet or soft x-ray photoelectron methods. In recent work a new method has been developed to probe camera-like snapshots of the ultraviolet photoelectron spectrum of bromine during dissociation. High order harmonics of a femtosecond Ti:sapphire laser are produced in a rare gas. A single harmonic (47 nm, 17th harmonic) is selected and used as the probe, while an ultrafast pump pulse at 400 nm is created by frequency doubling a portion of the 800 nm ultrafast laser. Figure 5 shows a time-resolved sequence of pump-probe spectra in bromine molecules following its photodissociation. The spectra reveal the clear formation of the photoelectron spectrum of the atoms, as well as the timescale for production of the free atoms. There are cross correlation (cc) features that occur because of above threshold ionization and permit a direct assessment of the time durations of the laser pulses and a weak feature at 8 eV that is attributed to the transient wave packet on the dissociative state prior to dissociation. An important result is the observation of an enhanced cross section for photoionization of the atomic species, compared to the molecules in the ground state. These results pave the way for a general new method to probe transient states in molecules, based on the familiar and powerful methods of photoelectron spectroscopy that have been so successfully employed for ground state analyses. (S.R. Leone)

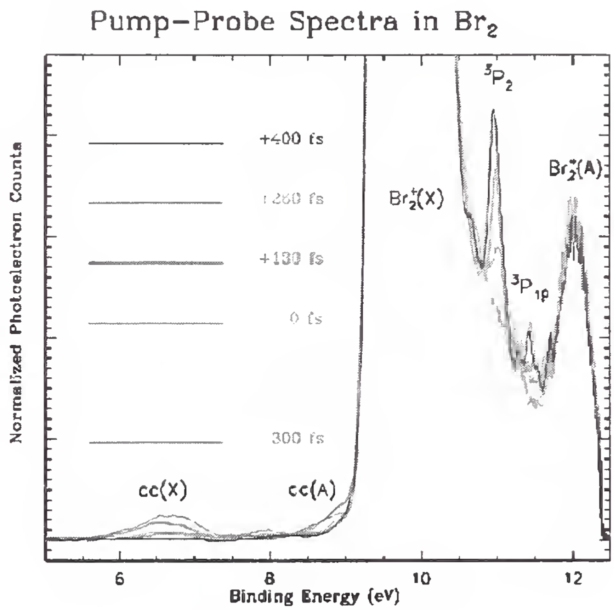


Figure 5. Femtosecond pump-probe spectra using soft x-ray radiation from a high order harmonic generation process as the probe on dissociating bromine molecules. The features labeled $Br_2^+(X)$ and $Br_2^+(A)$ are due to ionization of the Br_2 parent molecules. The features labeled $^2P_{2,1,0}$ are due to Br atoms upon dissociation. The cc are cross correlation features.

■ **Evolutionary Algorithms in Wave Packet Dynamics.** An evolutionary algorithm has been developed to optimize wave packet dynamics in ultrafast pump-probe experiments. The computer is given multiple sets of random phases versus frequency that are applied to a femtosecond pump pulse. These phases are imprinted onto the wave packet, causing the wave packet recurrences to be optimized at various time delays. The computer is asked to optimize the wave packet recurrences at a specific time delay. Thus some individual phase patterns are found to be better than others and are selected for reproduction by simple mutation. Multiple sets of mutated phase patterns are again tested for the desired optimization and after many generations a final set of phase patterns is obtained that contains the physics of the wave packet optimization process. Several new aspects have been pioneered. These are the first investigations of the effects of evolutionary optimization of the phases of frequencies on and off specific transition resonances, i.e., the separation of effects due to both resonant and non-resonant frequencies. Non-resonant frequencies are found to play a dramatic role both in Raman pumping, which requires two or more photons, and in the time-dependent amplitude coefficients that occur within the time duration of the laser pulse. By programming the algorithm to optimize specific beat frequencies as well as the overall wave packet recurrences, it is possible to optimize specific high order processes, such as a fourth order Raman pumping process, to enhance single quantum beats. These results will be important for future work on manipulating molecular wave packets to create quantum computing algorithms, such as Controlled NOT. (S.R. Leone)

■ **Growth of Quantum Dot Materials.** The formation of Ge nanodots on Si(100) occurs by strain-induced mechanisms (Ge is 4% larger than Si) and obeys the Stranski-Krastanov (SK) growth mode: a wetting layer (3-5 layers) is followed by the formation of three-dimensional Ge structures. Quantitative studies of Ge island size distributions and their shape transformations, including huts → pyramids → domes → superdomes and shape changes due to annealing of the islands under the influence of surfactants, have been achieved by molecular beam epitaxial growth and atomic force microscopy (AFM) post-analysis. For device applications, it is important to attain control over the size and spatial distributions of self-assembled nanostructures. The Ge growth experiments are also carried out on patterned silicon substrates (mesas formed by electron beam lithography followed by etching), for specific positioning of the dots. In fig. 6, a two-dimensional array of aligned 85 nm diameter self-assembled dome-type Ge islands is shown on the tops of lithographically patterned Si(001) mesas with a 140 nm period. A "one island on one mesa" relationship is clearly achieved. This density of islands is higher than can normally be produced on unpatterned silicon, where island coalescence usually occurs well before this density is possible. Preferential growth on the tops of the mesas most likely occurs because the Si mesa tops are deformable, fulfilling a strain relaxation condition. In this work, pyramid-type islands as small as 25 nm are also aligned on the mesa tops, and no limit to the size reduction of the islands is apparent, being controlled mainly by the size of the etched features that can be introduced. (S.R. Leone)

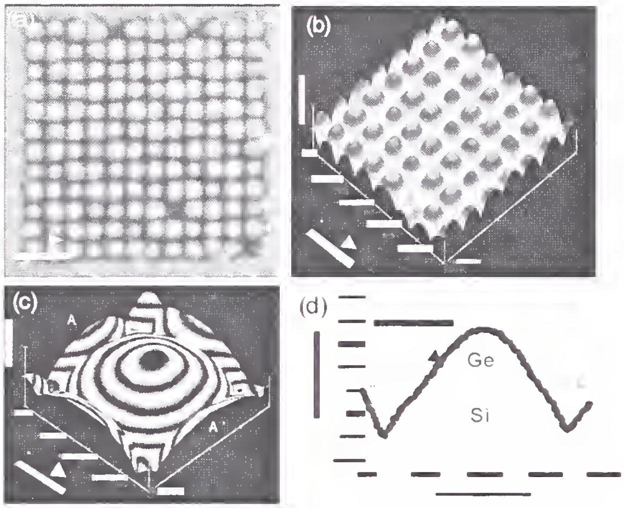


Figure. 6. 2D array of self-assembled Ge dots on lithographically patterned Si(001). Deposition of 6 ML Ge at 850 K. (a) 2 μm × 2 μm AFM image, showing one island at the center of each mesa. (b) 3D AFM image showing the uniformity of the dome structures. (c) Contour map showing the square base of one island in the [110] direction. The base direction is independent of the lithographic grid direction selected. (d) Side facets [114] of a Ge island on a mesa.

■ **New Instrument to Study Growth of InGaN Materials.** A new instrument has been fabricated and developed for the growth of InGaN materials. This apparatus has an *in situ* scanning tunneling microscope to interrogate the growing samples for the formation of three dimensional InN islands. The formation of these islands is crucial to the high efficiency of these materials for light emission, because the islands act as highly effective traps for carriers, despite large numbers of defects in the material itself. The ability to grow the material with uniform island sizes and spatial distributions will be a key aspect of new work to be undertaken. (S.R. Leone and S.T. Cundiff)

■ **Simultaneously Trapping and Cooling of Bosons and Fermions.** An apparatus is being built to simultaneously trap and cool a mixture of atoms that are bosons and atoms that are fermions. With this capability we will be able to investigate new phenomena in a mixed Bose-Fermi quantum gas. We have demonstrated the first two-species ^{87}Rb-^{40}K magneto-optical trap. This will serve as the initial stage for cooling the mixture to quantum degeneracy. We have loaded the precooled atoms into a purely magnetic trap. In the near future, the magnetically confined gas will be moved to a higher-vacuum portion of the chamber where it will be further cooled via forced evaporation and sympathetic cooling. (D.S. Jin)

■ **Exploring a Quantum Degenerate Gas of Fermionic Atoms.** An ultracold, degenerate Fermi gas of atoms provides a unique quantum system in which to explore the impact of Fermi-Dirac statistics. Using ^{40}K atoms in two different spin-states, we have experimentally realized an interacting Fermi gas and have begun exploring the dynamical behavior of this new system. An exciting prospect for the two-component Fermi gas is the possibility of a phase transition to a superfluid state, whose underlying physics is similar to superconductivity in metals. To explore this possibility we are investigating a predicted magnetic-field Feshbach resonance, which would allow experimental control of the interactions between atoms. The Feshbach resonance is predicted for spin states that cannot be held in a typical magnetic trap. Therefore we have loaded the ultracold gas into a far-off-resonant optical trap and have used RF adiabatic rapid passage to transfer the atoms to the appropriate spin states. We can now apply a uniform magnetic field of up to 250×10^{-4} tesla (250 Gs) and have seen preliminary evidence for the Feshbach resonance. (D.S. Jin)

■ **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 nm to 30 nm resolution, and under typical operating conditions, more like 100 nm resolution. An alternative we actively explored was to develop new methods in *apertureless* near field scanning optical microscopy, which already have demonstrated resolution improvements down to the 2 nm 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) sensitive resonant scattering light and/or fluorescence detection of the molecules subsequent to the excitation event. (A.C. Gallagher and D.J. Nesbitt)

■ **Scattering/Extinction Near Field Microscopy.** As a necessary first effort, these new apertureless NSOM methods have been used to evaluate the scattering cross sections of AFM tips in the presence of an evanescent wave as a function of tip distance above the surface. This has yielded the first absolute cross sections for near-to-far field scattering with well-characterized probe shapes, which are crucial in providing "benchmark" data for testing quantitative models of near field interactions. These methods were next used to obtain near field images of Au nanospheres at <5 nm resolution by resonant scattering of 543 nm light near the plasmon resonance. These studies determined that the combination of AFM tip + particle leads to a scattering enhancement of over 4000-fold from that of the bare Au nanospheres. Such data again provides important benchmarks against which to test theoretical models. (D.J. Nesbitt)

■ **Fluorescence Near Field Microscopy.** As a most recent achievement, these new apertureless NSOM methods have been extended into the domain of near field *fluorescence* microscopy domain, where the Si AFM tips are used to influence the near field excitation of dye doped nanospheres (on the 20 nm scale) or even down to semiconductor CdSe quantum dots (6 nm scale). The resulting fluorescence is imaged with a high numerical aperture microscope and fiber coupled avalanche photodiode combination. The data indicates substantial increase in the fluorescence from these molecules in the near field presence of the laser excited AFM tip, with spatial resolution that appears to be fully limited by the 5 nm tip radius of curvature. A simple electrostatic analysis of these data is consistent with a roughly 30-fold enhancement of electric field at the tip, which translates into a nearly 10^3-fold enhancement of the near field laser intensity. (D.J. Nesbitt and A.C. Gallagher)

■ **Near-Field Theoretical Modeling.** A new program in theoretical modeling of the apertureless NSOM data has obtained results based on modeling of the AFM tip, prism surface, and evanescent laser field by discrete electrostatic multipoles, and matching boundary conditions at the respective interfaces with least squares methods. Most importantly, these calculations can be converged for realistic elongated tip shapes that incorporate the lightening rod antenna effect and the actual exponential drop off of the evanescent fields. The results indicate (i) a significant enhancement of the fields near the tip, (ii) a strong sensitivity to the length of the tip elongation, and (iii) a limiting value of the field enhancement of $\kappa \approx 30$ for tip lengths greater than the 1/e evanescent decay. This value is in remarkably good agreement with what is observed experimentally. Furthermore, this analysis indicates a significant contribution to near field enhancement from "image dipoles" generated in the prism when the laser polarized AFM tip approaches within approximately one tip radius (5 nm) of the surface ("Narscissus effect"). (D.J. Nesbitt)

■ **Single Molecule and Single Quantum Dot Confocal Microscopy.** Spawned in conjunction with the NSOM efforts, we have been developing new capabilities in high sensitivity detection and spectroscopic characterization of single molecules based on laser excitation and fluorescence detection via scanning confocal microscopy, coupled with high sensitivity avalanche detection and/or a CCD array spectrometer. These methods have been used to investigate the photophysical dynamics of individual nanostructures, in particular focusing on ZnS overcoated CdSe and InP quantum dots on fused silica and glass surfaces. Particularly relevant has been the detailed studies of fluorescence intermittency or "blinking" of individual quantum dots, which begin to provide detailed kinetic information on electron hole pair ejection and recombination from single quantum dot structures. The distribution of time scales over which these ejection/recombination events occur spans an enormous dynamic range (microseconds to minutes), which can be statistically analyzed to show that the kinetics is intrinsically non-exponential, with "rates" varying over 5-6 orders of magnitude. (D.J. Nesbitt)

■ **Single Molecule Microscopy and Characterization of Biomolecules.** The new single molecule microscopy capability described above has been exploited in new directions that involve biophysical applications. We have utilized confocal methods to study green fluorescent protein (GFP), and initiated studies of intercalation kinetics of fluorescent dye molecules into DNA strands tethered to surfaces by biotin-streptavidin interactions. We are also developing tools based on wide field illumination and cooled CCD array cameras to image electrophoresis of single biomolecules in agarose gels. Finally, we are building up new time resolved capabilities for single biomolecule fluorescence detection in liquids utilizing polarized fluorescence resonant energy transfer (FRET) and burst integrated fluorescence (BIFL) methods. Monitoring the frequencies, polarization, and fast time correlations betweens the fluorescence photons emitted will allow one to watch relative distance and orientation of fluorescent donor/acceptor "tagged" biomolecules, and thereby probe kinetics of conformational changes in real time. (D.J. Nesbitt)

■ **Reaction Dynamics at the Gas-Liquid Interface.** A major fraction of chemical reactions of industrial, commercial, and environmental importance occur at the gas-liquid interface, ranging from atmospheric processing of ozone to rapid detonation in internal combustion engines. Despite this importance, the tools for exploring reaction dynamics at the gas-liquid interface are remarkably limited. A new program of study based on direct IR laser absorption to investigate quantum-state-resolved dynamics of reactions at the gas-liquid interface has been initiated. The first test system has been F atom reactive scattering from long chain liquid hydrocarbons (essentially low vapor pressure pump oils), which leads to HF(v,J) formation that is detected via direct IR laser absorption. Since the F atom source is pulsed and the HF detection is time resolved, this permits the dynamics of "direct" reactive scattering vs slower temporarily trapped interfacial reactions to be distinguished with full quantum state resolution of the products. (D.J. Nesbitt)

■ **High Resolution IR Laser Spectroscopy in Plasmas.** The overwhelming majority of all chemical processes occur via fast bimolecular reactions involving molecular species with unpaired electrons, i.e., free radicals. The reactivity of these species makes them especially hard to detect and study in detail. Of special interest are methods of spectroscopically characterizing these radicals at low temperature and high resolution, which is a crucial prerequisite for laser remote sensing of these species in the much more complicated "real world" environments of plasmas, combustion, etching, and so on. We are developing methods to combine the advantages of (i) low temperature expansions in slit supersonic jets with (ii) pulsed electrical discharges to produce unprecedentedly intense sources of molecular radicals under the low temperature (10 K to 20 K) and long absorption path environment ideally suited for direct absorption laser spectroscopy. We exploit this source for high resolution spectroscopic investigations of open shell hydrocarbon species (such as ethyl radical), as well as jet cooled molecular ions (such as protonated H_2, CH_4, and HCCH). As one example, vibrational spectra of H_3^+, H_2D^+, HD_2^+, and D_3^+ in the adiabatic approximation all derive from motion on the same Born Oppenheimer potential surface, which for a two-electron problem can be calculated to near spectroscopic accuracy. Comparison of high resolution spectra for these different mass combinations therefore provides direct evidence for *non-adiabatic*, Born Oppenheimer breakdown in the various isotopic mass combinations (D.J. Nesbitt)

■ **State-to-State Reaction Dynamics.** 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. We are making major advances in this area by exploiting (i) slit discharge technology as an intense source of jet cooled radicals and (ii) shot-noise-limited infrared laser absorption in order to explore quantum state-to-state reactive scattering studies in crossed supersonic jets. The initial focus has been on hydrogen abstraction reactions $F + RH \rightarrow HF(v,J) + R$, where the nascent rovibrational product states of HF can be sensitively detected via direct absorption methods. The crucial 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 $> 10^5$ to 10^6 fold better than previous crossed beam time-of-flight studies. These high resolution studies reveal major dynamical insights even for "simple" atom + diatom systems. For example, F + HD product state distributions have yielded direct evidence for Feshbach resonances corresponding to fleetingly bound vibrational states of the FHD complex with the H atom bouncing back and forth between the F and D atoms. These so called "transition state resonances" have been theoretically predicted but proven extremely elusive to detect experimentally without full quantum-state-resolved reactive-scattering methods. (D.J. Nesbitt)

■ **Atmospheric and Environmental Chemistry.** There has been an ongoing effort towards reaction dynamics relevant to atmospheric chemistry, direct IR laser absorption of highly reactive radicals. One important target has been chemical chain reaction depletion of ozone in the lower stratosphere, based on the ubiquitous reactions between OH, HO_2 and O_3, which is studied by excimer laser photolytic generation of OH radicals in a fast flow reactor, with time-resolved high resolution IR laser absorption over a long flow path length as a direct measure of OH, HO_2 radical concentrations and therefore the relevant rate kinetics. Most importantly, these IR based methods completely circumvent problems due to UV photolysis of ozone, which plagues conventional LIF detection methods for OH radicals. Consequently, this IR laser apparatus uniquely permits such reactions to be explored down to temperatures crucially relevant to the stratospheric models of the atmosphere. Other projects on this apparatus include studies of formation and energy transfer of highly rotationally excited OH(v,N 30), whose remarkable and highly non-equilibrium presence has been recently detected via IR emission from the upper atmosphere. (D.J. Nesbitt)

■ **Particle Growth in Deposition Discharges.** Gas discharges are frequently used to deposit thin films, for purposes as diverse as making optical or protective coatings, or producing semiconductors. Silicon-based semiconducting films, used for liquid-crystal displays, copiers, paper readers, and photovoltaics, are normally deposited from discharges in (primarily) silane gas. Silicon particles are produced in the plasma region of these discharges, and they can have a major influence on the discharge and device properties. We have developed the first quantitative model for the cause, speed, and efficacy of this particle growth, as well as for how the growth depends on discharge parameters. This model has been guided by, and has explained, laboratory data on 10 nm to 50 nm diameter particles, as well as data from another laboratory that detected the very light negative ions ($Si_nH_m^-$, $n < 10$) that initiate the particle growth. In both experiment and theory, thermophoresis has been shown to be a dominant mechanism controlling particle growth and survival in deposition discharges. This improved understanding has important implications for the design of thin-film coaters, especially those used for Si-based films. (A.C. Gallagher)

■ **Controlled Phase Coherence between Independent Femtosecond Lasers.** This recent breakthrough has enabled us for the first time ever to phase-lock together two independent mode-locked lasers. By creating coherence between two mode-locked lasers, we open the door to a wide-reaching variety of applications. For example, in applications where quantum coherent control is desired, coherent light may be needed in several disparate regions of the optical spectrum. However, current broad-band ultrafast laser systems generate a fractional bandwidth on order of a mere 30%. This bandwidth may be increased using various nonlinear techniques, but poor conversion efficiency limits its real-life application. Our approach enables the production of different wavelengths of light most efficiently and cleanly by using completely independent laser systems. The output from the laser systems can now be synchronized and phase-locked, resulting in a coherent composite field at exactly the frequencies of interest, with independent control of respective powers and relative optical phases, frequency chirps, and so on. One specific example of interesting science enabled by our breakthrough is to explore the interplay of two distinct regimes of quantum dynamics in a molecular system where one laser (red part of the spectrum) manipulates the ground state potential surface while another laser (blue part of the spectrum) controls the electronic wave function that would in turn favorably influence the ground state motion. Such exploration of two distinct regimes of quantum dynamics and of their mutual influence under a controlled fashion will surely be a most interesting part of quantum coherent control studies. (J. Ye)

■ **Pulse Shortening by Coherent Stitching of Separate Spectra for Different Lasers.** Current pulse-shaping techniques are limited primarily by two things: available coherent bandwidth, and the bandwidth over which group-velocity dispersion may be managed. By using independent mode-locked lasers with different center wavelengths, dispersion in each laser system can be managed separately, and the various beams can then be combined, synchronized, and phase-locked to create the shortest pulse. Alternatively, dispersion over the bandwidth could be manipulated to create an arbitrarily shaped optical waveform, paving the way for an ultimate "optical waveform synthesizer" machine. An important issue is to demonstrate control over the phase profile across the entire synthesized spectrum, namely pulse shaping. For example, a flat spectral phase profile is a prerequisite for generation of ultrashort pulses, while an arbitrary desired profile will be needed for coherent control applications. Under the current control scheme, we will be able to perform arbitrary pulse shaping over the entire phase coherent spectrum by controlling not only the phase slips between the two lasers but also their relative absolute phases. (J. Ye)

■ **Optical Frequency Metrology.** Recent work has shown that by broadening the output of a Ti:sapphire laser with a microstructure optical fiber, a comb consisting of millions of stabilized CW lines can be generated. This comb is limited in extent because of the nature of the non-linear process used for its production. Our new phase-locking technology can be extended to coherently lock together as many of these laser combs as desired, using different laser mediums as required. Other applications include mid-infrared light generation through difference frequency mixing, novel pump-probe experiments requiring synchronized laser light, and x-rays or electron beams from synchrotrons, particle accelerators with phase locked pulsed laser arrays, and so on. A recent development in our lab has reduced the timing jitter between two independent lasers to be below 1 fs, an important benchmark for further work on phase coherence of fs lasers. (J. Ye)

■ **Demonstration of an Optical Clock.** The first experimental success of a reliable clock operation based on an optical frequency standard has been demonstrated. This breakthrough is brought about by the recent merger of precision frequency metrology and ultrafast science. We have pushed the frontier to the next level where a single stabilized cw laser controls the entire optical comb over more than an octave bandwidth at a precision level of 10^{-15}. We have derived an rf clock signal of comparable stability to the optical standard itself (5×10^{-14} at 1-s) over an extended period. We have effectively demonstrated that with an appropriately chosen optical standard, we can establish an optical frequency grid with lines repeating every 100 MHz over an octave bandwidth and with every line stable at the one Hz level. And it is clear now that with a mature technical solution to the "gearbox problem" at hand, all future progress in optical and rf domain standards can be utilized in both spectra. Optical frequency standards now have truly become general purpose laboratory tools for physicists across many different disciplines. Some specific applications include tests on gravitational physics, searches for time-dependent variation of fundamental physical constants, precision atomic and molecular spectroscopy, and the combined time and length metrology. Furthermore, our work shows the first experimental demonstration of true orthogonal control of the wide-bandwidth optical comb. This important technological achievement brings the entire femtosecond comb under tight control and makes it a reliable tool. This accomplishment in the clockwork mechanism will impact any future development of optical clocks. (J. Ye)

■ **Ultrahigh Resolution Spectroscopy Using Femtosecond Laser.** Theoretical work has explored the aspect of novel high resolution spectroscopy employing a femtosecond laser. A phase-coherent wide-bandwidth optical comb is shown to induce the desired multi-path quantum interference effect for the resonantly enhanced two-photon transition rate. The analysis carried out in both the frequency and time domains makes the fundamental connection between the two physical pictures. Our calculation has provided a solid link between the time domain carrier-envelope phase and the frequency domain carrier-frequency offset. The consequence of these results was shown in terms of absolute control of both degrees of freedom for the fs comb, namely the comb spacing and the carrier offset frequency. The multi-pulse interference in the time domain gives an interesting variation and generalization of the two-pulse based temporal coherent control of the excited state wavepacket. (J. Ye)

■ **Manipulation of Molecular Wavepackets.** We use precision control of independent femtosecond lasers to develop a general purpose laboratory tool for coherent quantum control in manipulation of molecular wavepackets. A project is underway to explore the use of cold molecules in ultrahigh resolution spectroscopy and in the study of molecular dynamics. Femtosecond-laser-based precision molecular spectroscopy is expected to yield information on molecular structure 1000 times more accurate than previous results. (J. Ye)

■ **Precision Spectroscopy of Atoms and Molecules.** We are pursuing precision spectroscopy on cold samples of Rb atoms. An optical frequency standard based on a two-photon transition in the cold Rb atoms will be established. We are also investigating coherent interactions between a stable ultrafast laser and the cold atoms. A broadly tunable precision spectrometer has been built to study the unexplored regions of the iodine spectrum near its dissociation limit. We have discovered new and interesting behavior in the change of the hyperfine interactions of the iodine molecules. Many new transitions have been identified with excellent potential of being the next generation simple optical frequency standards. (J. Ye)

■ **Optical Frequency Measurement.** During the past year the femtosecond method of optical frequency measurement has been brought to an astounding level of robustness, convenience, and accuracy. We have developed one excellent method for orthogonalizing the control of the fs laser's two frequency parameters, the pulse repetition rate and the carrier/envelope phase slip rate, otherwise called the carrier/envelope offset frequency. This method allows us to completely transfer to the fs laser comb the attained stability of a stable optical frequency reference source, in our case the Nd:YAG laser stabilized to a strong, narrow molecular Iodine resonance. With colleagues in NIST Time and Frequency Division, we have compared the frequency of an rf signal derived from our optical source directly with the NIST Hydrogen maser signal which reaches us from NIST by the Boulder Regional Area Network (the BRAN optical fiber). The frequency variations for times less than ~100 s are just equal to the stated uncertainty of the Hydrogen maser: thus we are entering the domain where optical sources provide frequency stability completely equal or superior to that obtainable with traditional high-end microwave approaches. (J.L. Hall)

■ **New, Small, Absolute, and Highly Portable Gravity Instrument.** Dramatic progress was made during the past year in regards to this new, cam-based absolute gravimeter. This small, fast, portable, and simple-to-use instrument uses a rotating cam to create the following: a release, a 2 cm free-fall drop, a soft catch, and then a return to the starting position--with all of this requiring only 0.3 seconds. The instrument inherently yields a high measurement rate (3.3 drops per second) that compensates-in terms of measurement accuracy -for the relatively short dropping length. Furthermore, by employing a second co-rotating cam to drive an auxiliary mass it is possible to keep the instrumental center-of-mass fixed. In this way recoil effects having to do with both the release of the mass and the accelerations of the mass-carrying carts can be, in principle, completely eliminated. Measurement results obtained during this past year are extremely encouraging. Data taken at a good site (Table Mountain) was reproducible at the several times 10^{-8} m/s of precision. Data taken at a poor site (bad floor and noisy environment) was reproducible at the 10^{-7} m/s level. We are presently looking at the effects of misalignments in the mechanical system which might explain this performance. (J.E. Faller)

■ **Newtonian Constant of Gravitation.** Our approach to measuring this fundamental constant involves measuring small length changes by sensing frequency changes in a laser that is locked to a Fabry-Perot cavity whose mirrors are located in two freely hanging masses. This laser is in turn beat with another laser that is locked to a fixed cavity that monitors the separation between the suspension points of the two hanging Fabry-Perot mirrors. When a 500 kg mass of tungsten is moved and appropriately positioned nearby, it deflects the freely hanging (70 cm long) pendulums. G can then be determined by combining the measured small frequency-sensed changes in this cavity's length with carefully made measurements of the experiment's geometry.

During the past year, assembly of the apparatus was completed and a considerable amount of data was taken. Preliminary measurements indicate that—subject to our understanding of all systematic errors—an uncertainty of below 5 parts in 10^5 can be obtained. A number of as yet to be understood systematic effects have however appeared in addition to strong evidence of a magnetic contaminant in one of the two freely hanging masses. The plan is first to address the systematic effects [which should produce an already interesting experimental accuracy for this constant (approaching 1 in 10^4)] and then to replace the contaminated mass and take additional data with the anticipation that an additional factor of 2 or 3 improvement in accuracy will result. (J.E. Faller)

AWARDS AND HONORS

NATIONAL AWARDS AND HONORS

R.S. Caswell of the Ionizing Radiation Division was the first recipient of the **Council on Ionizing Radiation Measurements and Standards' Distinguished Achievement Award** "for his distinguished contributions to national and international ionizing radiation standards programs."

C.W. Clark of the Electron and Optical Physics Division was elected to **Fellowship in the American Association for the Advancement of Science** "for his contributions in theoretical physics applied to diverse systems, including highly-excited atoms and many-body phenomena of gaseous Bose-Einstein condensates."

E.A. Cornell of the Quantum Physics Division (jointly) received the **2001 Nobel Prize in Physics** for "the achievement (in 1995) of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates."

B.M. Coursey of the Ionizing Radiation Division, was inducted as a **2000 Fellow of the American Association of Physicists in Medicine** "for his distinguished contributions to medical physics."

Katharine B. Gebbie was recognized by the Division of Atomic, Molecular, and Optical Physics of the American Physical Society, for her "leadership role in fostering excellence in AMO science."

T. Germer of the Optical Technology Division received the **Sigma Xi Award**, "for his pioneering work in developing new techniques using optical scattering to elucidate detailed surface properties."

D. Gillaspy of the Atomic Physics Division, was offered a Distinguished Visiting Fellowship (http://143.117.13.20/ircep/dvf.html) from the Queens University, Belfast.

D.S. Jin of the Quantum Physics Division received the **Maria Goeppert Mayer Award** for "her innovative realization and exploration of a novel quantum system, the degenerate Fermi atomic gas, and the scientific promise portended by her pioneering work."

Y.-K. Kim of the Atomic Physics Division was a Visiting Professor, National Institute for Fusion Science, Toki, Japan, September 3- October 2, 2001 (originally planned for three months, September-November 2001, but was interrupted after the terrorist attack in the U.S.)

W.Ott of the Physics Laboratory office was presented an award by the **NIST Chapter of Sigma Xi** for "outstanding service in support of NIST scientists."

B.N. Taylor of the Physics Laboratory Office received the **CODATA Prize 2000 Award** from the Committee on Data for Science and Technology (CODATA) "for his scientific skills and extraordinary accomplishments related to his determination of the fundamental physical constants, his management of the international consensus process, and his insights into the meaning and nature of uncertainty in scientific data at the most fundamental level."

B.N. Taylor received a **2000 Distinguished Executive Rank Award.** The President of the United States of American conferred on him the rank of Distinguished Executive in the Senior Executive Service "for sustained extraordinary accomplishment in management of programs of the United States Government and for leadership exemplifying the highest standards of service to the public, reflecting credit on the career civil service.

C.J. Williams of the Atomic Physics Division was a Visiting Professor (1 month), Laboratorie Aime Cotton, University of Paris South, Orsay, France

D. Wineland of the Time and Frequency Division was recently awarded the 2001 **Arthur L. Schawlow Prize** in Laser Science by the American Physical Society "for an extraordinary range of pioneering studies combining trapped ions and lasers."

DEPARTMENT OF COMMERCE AWARDS

J.C. Bergquist, S.A. Diddams, L. Hollberg, and **C.W. Oates** of the Time and Frequency Division were awarded the **Department of Commerce Gold Medal** "for outstanding achievement in developing world-leading optical-frequency standards and the means for relating their outputs to other frequencies."

S.T. Cundiff, J.L. Hall, and J. Ye of the Quantum Physics Division were awarded the **Department of Commerce Gold Medal** for "outstanding achievement in developing world-leading optical frequency standards and the means for coupling their outputs to other frequencies."

L.R. Karam of the Ionizing Radiation Division received **the Department of Commerce Bronze Medal** "for exceptional leadership of the NIST radioactivity standards program for nuclear medicine and environmental radioactivity measurements."

C.S. Soares of the Ionizing Radiation Division, received **the Department of Commerce Silver Medal** "for his international leadership in developing standards to promote therapeutic applications of radioactive sources for cancer and heart disease."

NIST NAMED AWARDS

J.C. Bergquist, S. Jefferts, and **D. Wineland**, of the Time and Frequency Division received the **Edward Uhler Condon Award** for their Physics Today cover article entitled "Time Measurement at the Millennium," which lucidly describes current and future atomic-clock technology.

A. Farrell, E. Fein, M. Furst, R. Graves (posthumously), E. Hagley, A. Hamilton, L. Hughey, R. Madden and R. Vest of the Electron and Optical Physics Division shared the **Judson C. French Award** "for their exceptional achievement in constructing the NIST Synchrotron Ultraviolet Radiation Facility, SURF III."

D.S. Jin of the Quantum Physics Division received the **2001 Samuel Wesley Stratton Award** for "her pioneering creation of a degenerate gas in a dilute atomic vapor, a microscopic model for important scientific and technological materials."

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INVITED TALKS

LABORATORY OFFICE

Gebbie, K.B., "Collaboration between NPL and the National Institute of Standards and Technology," National Physical Laboratory Centenary Meeting, London, UK, November 2000.

Gebbie, K.B., "Review of the Physics Laboratory – A Presentation to the Visiting Committee on Advanced Technology," Boulder, CO, December 2000.

Gebbie, K.B., "From Light Bulbs to LEDs: How We Measure What We See," Centennial Standards Symposium on Standards in the Global Economy: Past, Present, and Future, NIST, Gaithersburg, MD, March 2001.

Gebbie, K.B., "A Century of Physics at NIST," American Physical Society Annual March Meeting, Seattle, WA, March 2001.

Gebbie, K.B., "Avenues to White Light," National Research Council Board on Science, Technology, and Economic Policy Symposium on Partnerships for Solid State Lighting, Washington, DC, March 2001.

Gebbie, K.B., "Broadening the Demographics at NIST," American Physical Society Annual April Meeting, Washington, DC, April 2001.

Gebbie, K.B., "A Third of a Century at NIST," Women in Optics Working Group, International Society of Optical Engineering, San Diego, July 2001.

Ott, W.R., "AMO Physics at NIST: What's New," National Research Council Committee on Atomic, Molecular, and Optical Physics, Washington, DC, April 2001.

Ott, W.R., "100 Years of Optical Science and Metrology at NBS/NIST," SPIE Conference, San Diego, CA, August 2001.

ELECTRON & OPTICAL PHYSICS DIVISION (841)

Clark, C.W., "Theory and experiment in Bose-Einstein condensation," Symposium on Quantum Control of Atoms and Fields, University of Rochester, Rochester, NY, October 2000.

Clark, C.W., "Soliton and vortex excitations of Bose-Einstein condensates," March Meeting of the American Physical Society, Seattle, WA, March 2001.

Clark, C.W., "Superfluid and laser analogies in quantum gases," 2001 Quantum Electronics and Laser Science Conference, Baltimore, MD, May 2001.

Clark, C.W., "Soliton and vortex excitations of Bose-Einstein condensates," Quantum Optics V, Koscielisko, Poland, June 2001.

Edwards, M., "Optical Manipulation of Bose-Einstein Condensates," Quantum Electronics, Atomic and Molecular Physics Seminar, SUNY Stony Brook, Stony Brook, NY, November 2000.

Edwards, M., "Optical Manipulation of a Bose-Einstein Condensate," Department of Physics, University of Georgia, Athens, GA, February 2001.

Edwards, M., "Optical Manipulation of a Bose-Einstein Condensate," General Relativity Group, Department of Physics, University of Maryland, College Park, MD, May 2001.

Feder, D.L., "Vortices in Trapped Bose-Einstein Condensates," Quantum Optics and Condensed Matter Seminar, University of Toronto, Canada, October 2000.

Feder, D.L., "Solitons, vortices, and rings in trapped Bose-Einstein condensates," Workshop on Computational Methods for Few-Body Dynamical Systems, Gaithersburg, MD, November 2000.

Feder, D.L., "Solitons and vortex rings in trapped Bose-Einstein condensates," 31st Winter Colloquium on the Physics of Quantum Electronics, Snowbird, Utah, January 2001.

Feder, D.L., "Vortices and Bose-Einstein condensation," Interdisciplinary Problems in Chemistry and Physics Seminar, University of Maryland, College Park, MD, February 2001.

Feder, D.L., "Vortices in trapped Bose-Einstein condensates," Harvard/MIT Center for Ultracold Atoms, Harvard University, March 2001.

Feder, D.L., "Superfluid to solid crossover in a rotating Bose-Einstein condensate," Intl. Conf. on the Theory of Quantum Gases and Quantum Coherence, Salerno, Italy, June 2001.

Grantham, S., "EUV Metrology at NIST," Workshop on Metrology and Synchrotron Radiation, Orsay, France, May 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," Princeton University, Princeton, NJ, January 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," Case Western University, Cleveland, OH, February 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," MIT, Boston, MA, February 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," McMaster, University, Toronto, Canada, February 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," University of Florida, Gainesville, FL, February 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," University of Pennsylvania, Philadelphia, PA, February 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," University of California Los Angeles, Los Angeles, CA, March 2001.

Hudson, E.W., "Information from Imperfection: Imaging Atomic Scale Perturbations in High Temperature Superconductors," University of California Santa Barbara, Santa Barbara, CA, March 2001.

Hudson, E.W., "Evidence for Nanoscale Phase Separation and Granular Superconductivity in Bi-2212," Networks and Nanoscale Coherence in 2D Metals and HTSC 2001, Alberta, Canada, August 2001.

Levine, Z.H., "X-Ray Tomography of Integrated Circuit Interconnects: Past and Future," 27th Intl. Symposium for Testing and Failure Analysis, Santa Clara, CA, November 2000.

McClelland, J.J., "A Critical Look at Atom Lithography," DARPA Workshop on Non-Conventional Patterning below 50 nm, Arlington, VA, January 2001.

McClelland, J.J., "Laser Manipulation of Chromium Atoms," Atomic Physics Seminar, University of Bonn, Bonn, Germany, June 2001.

Pierce, D. T., "Spin-Polarized Electrons: How Measurement Development Advances Science and Technology," American Physical Society March Meeting, Seattle, WA, March 2001.

Tarrio, C., "Improvements to the NIST/DARPA EUV Reflectometry Facility," EUV Imaging Conference, SPIE Meeting, July 2001.

Tarrio, C., "Absolute EUV Metrology," NIST Centennial Session, SPIE Meeting, August 2001.

Unguris, J., "Scanning Electron Microscopy with Polarization Analysis (SEMPA) Imaging of Surface and Thin Film Magnetic Microstructure," American Physical Society March Meeting, Seattle, WA, March 2001.

Vest, R.E., "Some NIST Calibration Services in the Far and Extreme Ultraviolet Spectral Regions," Thermospheric, Ionospheric, and Geospheric Research (TIGER) Conf., Boulder, CO, June 2001.

ATOMIC PHYSICS DIVISION (842)

Browaeys, A., "Bose-Einstein condensation of metastable Helium," Gordon Research Conference, Williamstown, CT, June 2001.

Bryant, G.W. and W. Jaskolski, "Designing Quantum Dots and Quantum-dot solids," Advanced Research Workshop on Semiconductor Nanostructures, Queenstown, New Zealand, February 2001.

Bryant, G.W., "Nanooptics for the Nanoworld," Institute Seminar, University Nicholas Copernicus, Torun, Poland, April 2001.

Bryant, G.W., "Designing Quantum Dots and Quantum-Dot Solids," Institut fur Theoretische Physik, Universitat Hamburg, Hamburg, Germany, May 2001.

Bryant, G.W., "Designing Quantum Dots and Quantum-Dot Solids," National Research Council, Ottawa, Canada, May 2001.

Burnett, J.H., "Intrinsic Birefringence in 157 nm Materials," 2nd International Symposium on 157 m Lithography, Dana Point, CA, May 2001.

Burnett, J.H., "Intrinsic Birefringence in 157 nm Materials," SEMATECH CaF_2 Birefringence Workshop, San Francisco, CA, July 2001.

DeGraffenreid, W., "High Precision Laser Spectroscopy: Just Like Measuring the Distance Between Union College and Cal Poly Pomona to Five Millimeters," Union College Colloquia, Schenectady, NY, September 2001.

Gillaspy, J.D., "Recent Results from the NIST Electron Beam Ion Trap Project," Oxford University, Oxford, England, April 2001.

Gillaspy, J.D., "Applications of Highly Charged Ions in the Microelectronics Industry," X-ion Corporation, Paris, France, July 2001.

Helmerson, K., "Laser Cooling and Trapping of Atoms," Ethiopian Student Day, Washington, DC, February 2001.

Helmerson, K., "Photoassociation in a Condensate," Atomic Physics Seminar, University of São Paulo, São Carlos, Brazil, May 2001.

Helmerson, K., "Bose-Einstein Condensates in Optical Lattices," Brazilian Physical Society, Caxambu, Brazil, May 2001.

Helmerson, K., "Observation of Dynamical Tunneling," Workshop on Cold Quantum Gases, Zakopane, Poland, June 2001.

Helmerson, K., "Non-Linear Atom Optics," DAMOP, Storrs, CT, June 2001.

Helmerson, K., "Photoassociation in a Condensate," 15th International Conference on Laser Spectroscopy (ICOLS XV), Salt Lake City, UT, June 2001.

Helmerson, K., Hensinger, W.K., Häffner, H., Browaeys, A., Heckenberg, N.R., Holmes, C.A., McKenzie, C., Milburn, G.J., Phillips, W.D., Rolston, S.L., Rubinsztein-Dunlop, H., and Upcroft, B., "Cold atoms in an amplitude modulated optical lattice - dynamical tunneling," International Conference on Laser Spectroscopy in Snowbird, Utah, June 2001.

Julienne, P.S., "Threshold resonances: A key to cold collision physics," Physics Seminar, University of Texas at Austin, Austin, Texas, March 2001.

Julienne, P.S., "Threshold resonances: A key to cold collision physics," Seminar, Center for Ultracold Atoms, Harvard/MIT, Cambridge, MA, May 2001.

Julienne, P.S., "Threshold resonances: A key to cold collision physics," International Conference on Laser Spectroscopy, Snowbird, Utah, June 2001.

Julienne, P.S., "Collisions of Cold Group II Atoms," Workshop on Cold Atoms and Ultraprecise Atomic Clocks, Sandjberg, Denmark, September 2001.

Kim, Y.-K., "Excitation and Ionization of Neutral Atoms and Singly-Charged Ions," National Inst. for Fusion Science, Toki, Japan, September 2001.

Lett, P.D., "Atoms and Light: From Laser Cooled Atoms to Atom Lasers," Washington Philosophical Society Meeting, Washington, DC, April 2001.

Lett, P.D., "Photon Statistics of Lasers and Atoms," Coherence and Quantum Optics 8, Rochester, NY, June 2001.

Matyi, R.J., "Advanced X-ray Scattering Methods for Microelectronic Materials Characterization," Analytical Laboratory Mangers Council Meeting, Newport Beach, CA, March 2001.

Matyi, R.J., "High Resolution Diffuse X-ray Scattering by Protein Crystals – from *hkl* to 000," Michigan State University Workshop, Traverse City, MI, July 2001.

Mohr, P.J., "Fundamental Constants at NBS-NIST," APS Meeting, Seattle, Washington, March 2001.

Phillips, W.D., "Atom Optics with BEC," Physics Colloquium, Rice University, Houston, TX, February 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Houston Lecture, Rice University, Houston, TX, February 2001.

Phillips, W.D., "The Excitement of Science," Chesterfield County Schools, Richmond, VA, March 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Electrochemical Annual Society, Washington, DC, March 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Sigma Xi Presentation, Swarthmore, PA, March 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," The Society for Physics Students (SPS), Mary Washington College, Fredericksburg, VA, March 2001.

Phillips, W.D., "Optics with Matter Waves," Physics Department Colloquium, Swarthmore, PA, March 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Benson Lecturer, Miami University of Ohio, Oxford, OH, April 2001.

Phillips, W.D., "The Coldest Stuff There Is," Cherry Hill Elementary School, Cherry Hill, NJ, April 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," APS Physics Teacher Day, Washington, DC, April 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Ramapo College, Lecture in honor of Prof. Teodoro Halperin, Mahwah, NJ, April 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Sigma Zeta Lecture, Asbury College, Wilmore, KY, April 2001.

Phillips, W.D., "Quantum Computation," Annual meeting of the National Organization of the Advancement of Black Chemists and Chemical Engineers (NOBCCHE), Baltimore, MD, April 2001.

Phillips, W.D., "Super Cool Gases," Innovative Lives, Nobel Voices: Celebrating 100 Years of the Nobel Prize, Smithsonian National Museum of American History, Washington, DC, April 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," Physics Olympiad U.S. Team Training Conference, College Park, MD, May 2001.

Phillips, W.D., "The Coldest Stuff There Is," Wooton High School, Rockville, MD, May 2001.

Phillips, W.D., "Coherent Matter Wave Optics, Meeting of Nobel Laureates, Lindau, Germany, June 2001.

Phillips, W.D., "Almost Absolute Zero: The Story of Laser Cooling and Trapping," SURF Seminar, NIST, Gaithersburg, MD, July 2001.

Phillips, W.D., "The Best Clocks (and the Coolest Stuff) in the World," New NIST Employees Lecture, NIST, Gaithersburg, MD, July 2001.

Ratliff, L.P., "Surface modification with highly charged ions," International Symposium on Ion Atom Collisions," Ensenada, Mexico July 2001.

Reader, J. "Atomic Spectroscopy at NIST-2001," 46th Annual Meeting of SPIE, San Diego, CA, August 2001.

Rolston, S., "Quantum Computing with Neutral Atoms," University of Queensland, Brisbane, Australia, January 2001.

Rolston, S., "Quantum Computing with Neutral Atoms," Australia National University, Canberra, Australia, January 2001.

Rolston, S., "Quantum Information Processing with Atoms in Optical Lattices," Intl. Conference on Experimental Implementation of Quantum Computing, January 2001.

Rolston, S., "Entanglement in a BEC," Southwest Quantum Information Network Annual Meeting, Pasadena, CA, March 2001.

Rolston, S., "Nonlinear Atom Optics," Joint Atomic Physics Colloquium, Harvard University, Cambridge, MA, April 2001.

Rolston, S., "Ultracold neutral plasmas," ITAMP Workshop on Complex Phenomena with Rydberg Atoms, Cambridge, MA, April 2001.

Rolston, S., "Nonlinear Atom Optics" at the DAMOP Conference; London, Ontario, Canada, May 2001.

Sansonetti, C.J., Blackwell, M.M., and Saloman, E.B., "Infrared spectra of Ne, Kr, and Xe," Fourier Transform Spectroscopy 2001, Topical Meeting of the Optical Society of America, Coeur d'Alene, ID, February 2001.

Sansonetti, C.J., Blackwell, M.M., and Saloman, E.B., "Infrared spectra of the noble gases," 7th International Colloquium on Atomic Spectra and Oscillator Strengths, Belfast, Northern Ireland, August 2001.

Wiese, W.L., "Progress on Atomic Databases," 7th International Colloquium on Atomic Spectra and Oscillator Strengths, Belfast, Northern Ireland, August 2001.

Wiese, W.L., "The NIST Atomic Spectra and Ionization Cross Section Databases," 16th Atomic and Molecular Data Center Network meeting, International Atomic Energy Agency, Vienna, Austria, September 2001.

Wiese, W.L., "Trends in Atomic Spectroscopy," Physics Colloquium, University of Graz, Austria, September 2001.

Williams, C.J., "Quantum Computing with Neutral Atoms in Optical Lattices" INFM, University of Florence, Florence, Italy, February 2001.

Williams, C.J., "Ultracold Collisions and Clock Shifts in Rb and Cs," Time and Frequency Division, National Institute of Standards and Technology, Boulder, CO, February 2001.

Williams, C.J., "Quantum Computing and Optical Nanostructures" INFM, University of Pisa, Pisa, Italy, February 2001.

Williams, C.J., "An Introduction to Quantum Information and Computing" Physics Colloquium, Swarthmore University, Swarthmore, PA, February 2001.

Williams, C.J., "An Introduction to Quantum Information and Quantum Computing" Physics Colloquium, Georgia Tech, Atlanta, GA March 2001.

Williams, C.J. "Cs Feshbach Spectroscopy and Atomic Clocks" Physics Colloquium, National Institute of Standards and Technology, Gaithersburg, MD, July 2001.

OPTICAL TECHNOLOGY DIVISION (844)

Briggman, K.A., "Determination of Molecular Structure at Polymer/Glass Interfaces by Sum Frequency Generation," Northeast Regional Meeting of the American Chemical Society, Durham, NH, August 2001.

Brown, S.W., "Stray Light Characterizations for MOBY," 2001 Ocean Color Research Team Meeting, San Diego, CA, May 2001.

Bruce, S.S., "The Quality System for Calibration Services offered by the Optical Technology Division at NIST," NRC-INMS Canada, November 2001.

Chang, E.K., "Excitonic Effects in Nonlinear Optics," University of Modena, Modena, Italy, July 2001.

Chang, E.K., "Excitonic Effects in Nonlinear Optics," Physics Department Seminar, University of Rome Tor Vergata, Rome, Italy, July 2001.

Datla, R.U., "NIST Report to Committee on Earth Observing Satellites (CEOS) WGCV 18," ESA-ESRIN, Frascati, Italy, June 2001.

Eppeldauer, G.P., "Spectral Response Calibration of Infrared Detectors," Presentation at the Measurement Science Conference (MSC-2000), Anaheim, CA, January 2001.

Eppeldauer, G.P., "Photocurrent Measurement of PC and PV HgCdTe Detectors," Measurement Science Conference, Anaheim, CA, January 2001.

Germer, T.A., "Interpreting Light Scattering from Surfaces," Conference on Optical Manufacturing for Dual-Use, Huntsville, AL, February 2001.

Gibson, C.E., "Non-contact Thermometry in the Optical Technology Division at NIST," Thermal Solutions Conference, Orlando, FL, April 2001.

Goldner, L.S., "Single Molecule Probe," University of Maryland, May 2001.

Goldner, L.S., "Single Molecule Probe," SPIE meeting, San Diego, CA, August 2001.

Hanssen, L.M., "Infrared Spectrophotometry at NIST," National Physical Laboratory, New Delhi, India, November 2000.

Heilweil, E.J., "New Applications of Ultrafast, Terahertz and Chemical Imaging Spectroscopies," University of Wisconsin, Madison, WI, April 2001.

Heilweil, E.L., "FTIR Chemical Imaging Methods for Combinatorial Screening," AIChE National Meeting, Combinatorial Methods for Materials R&D, Systems Integration in High Throughput Experiments ATP Workshop, Los Angeles, CA, November 2000.

Heilweil, E.J., "Applications of Transient Infrared Spectroscopies," Invited Plenary Lecture, Time-Resolved Vibrational Spectroscopy X, Inst. or Mol. Science, Okazaki, Japan, May 2001.

Heilweil, E.J., "Using Broadband Infrared light for Ultrafast Spectroscopy and Chemical Imaging," SURF 2001 Summer seminar series, June 2001.

Hwang, J., "Imagining Nanostructures with Near-Field Scanning Optical Microscopy," National Institute of Allergy and Infectious Disease, NIH, Bethesda, MD, July 2001.

Jacox, M.E., "Chemical Reactivity of the Rare Gases," Euroconference Matrix 2001: The Chemistry and Physics of Matrix Isolated Species, Szklarska Poreba, Poland, July 2001.

Johnson, B.C. "Remote Sensing Support at NIST" SIMBIOS Science Team Meeting, Greenbelt, MD, January 2001.

Johnson, B.C., "Non-contact Thermometry in the Optical Technology Division at NIST," Thermal Solutions Conference, Orlando, FL, January 2001.

Kaplan, S.G., "Characterization of Infrared Optical Materials and Components for Spectroradiometric Sensor Systems," Symposium on Optics Manufacturing for Dual-Use, Huntsville, Alabama, April 2001.

Kaplan, S.G., "Overview of NIST-Industry Consortium on Optical Properties of Materials," SPIE Technical Group on Optical Materials and Optics Manufacturing Meeting, San Diego, CA, August 2001.

Miller, C.C., "Total Luminous Flux Calibrations of LEDs at NIST," Compound Semiconductor Manufacturing Expo, Hynes Convention Center, Boston, MA, July 2001.

Miller, C.C., "Luminous Intensity Calibrations and Colorimetry of LEDs at NIST," Compound Semiconductor Manufacturing Expo, Hynes Convention Center, Boston, MA, July 2001.

Ohno, Y., "CIE Fundamentals for Color Measurements," IS&T NIP16 International Conference on Digital Printing Technologies, Vancouver, Canada, October 2000.

Ohno, Y., "Color Issues of White LEDs," OIDA Workshop on OLED Solid State Lighting, Berkeley, CA, November-December 2000.

Ohno, Y., "Uncertainty in Sphere Photometry," A Tutorial lecture, CIE Expert Symposium on Uncertainty Evaluation, Vienna, Austria, January 2001.

Ohno, Y., "Numerical Method for Color Uncertainty," CIE Expert Symposium on Uncertainty Evaluation, Vienna, Austria, January 2001.

Plusquellic, D.F., "Cavity Ring-Down Enhanced Circular Dichroism and Rotationally Resolved UV Spectroscopy of Binaphthol," Chemistry Seminar Series, Wesleyan University, Delaware, OH, April 2001.

Plusquellic, D.F., "Windows GUI Program for the Rotational Analysis of Molecular Spectra," Mini-Symposium: Freeware, 56th International Symp. of Molecular Spectroscopy, Ohio State University, Columbus, OH, June 2001.

Rice, J.P., "NIST Activities in support of Space-Based Radiometric Remote Sensing," SPIE Conference: Harnessing Light: Optical Science and Metrology at NIST, San Diego, CA, August 2001.

Shaw, P.S., "Characterization of UV Detectors at Synchrotron Ultraviolet Radiation Facility (SURF III),"for the Synchrotron Radiation Instrumentation Conference 2001, Madion, WI, August 2001.

Shirley, E.L., "Aspects of practical radiometry: terminology, uncertainty, and physical optics," Measurement Science Conference (MSC2001), Anaheim, CA, January 2001.

Shirley, E.L., "Linear and Non-linear Optical Properties of Materials with the Bethe-Salpeter Equation," Ecole Polytechnique, Palaiseau, France, August 2001.

Shirley, E.L., "Inelastic x-ray Scattering and Detailed Core- and Valence-Excitation Spectra," Intl. Conference on Inelastic X-ray Scattering (IXS2001), Haikko, Finland, August 2001.

Yoon, H.W., "Non-contact Thermometry in the Optical Technology Division at NIST," Thermal Solutions Conference, Orlando, FL, January 2001.

IONIZING RADIATION DIVISION (846)

Adams, J.M., "Nuclear Science at the National Institute of Standards and Technology: A Historical Overview," 2000 American Nuclear Society/ European Nuclear Society International Meeting, Washington, DC, November 2000.

Adams, J.M., "PENTRAN Modeling for Design and Optimization of the Spherical-Shell Transmission Experiments," 2001 American Nuclear Society Annual Meeting, Milwaukee, WI, June 2001.

Adams, J.M., "A New Monte Carlo Tallying Methodology for Optimizing the NERI Spherical-Shell Transmission Experiment," 2001 American Nuclear Society Annual Meeting, Milwaukee, WI, June 2001.

Carlson, A.D., "NIST Nuclear Data Activities," Cross Section Evaluation Working Group Meeting, Brookhaven National Laboratory, Upton, NY, November 2000.

Carlson, A.D., "Requirements of the Neutron Cross Section Standards," Consultants' Meeting on Improvement of the Standard Cross Sections for Light Elements, International Atomic Energy Agency Headquarters, Vienna, Austria, April 2001.

Carlson, A.D., "The International Evaluation of the Neutron Cross Section Standards," Working Party on International Evaluation Cooperation Meeting, Santa Fe, NM, April 2001.

Carlson, A.D., "The NIST Nuclear Data Program," U.S. Nuclear Data Program Meeting, Brookhaven National Laboratory, Upton, NY, April 2001.

Collé R., "Activity Characterizations of Pure .-emitting Brachytherapy Sources," 13th International Conference on Radionuclide Metrology and Its Applications (ICRM2001), Braunschweig, Germany, May 2001.

Collé, R., "A Dual-compensated Cryogenic Microcalorimeter for Radioactivity Standardizations," 13th International Conference on Radionuclide Metrology and Its Applications (ICRM2001), Braunschweig, Germany, May 2001.

Coursey, B.M., "NIST Standards for Nuclear Medicine," 2000 American Nuclear Society/ European Nuclear Society Meeting, Washington, DC, November 2000.

Coursey, B.M., "National Standards for Intravascular Brachytherapy," Cardiovascular Radiation Therapy and Restenosis Forum, Washington, DC, February 2001.

Coursey, B.M., "Standards of Radium-226: From Marie Curie to the ICRM," 13th International Conference on Radionuclide Metrology and Its Applications (ICRM2001), Braunschweig, Germany, May 2001.

Desrosiers, M.F., "Using Bones and Teeth to Measure Radiation Doses," Chemistry Department Seminar, University of California, Santa Barbara, CA, January 2001.

Desrosiers, M.F., "*e*-Calibrations: Using the Internet to Deliver Calibration Services in Real Time at Lower Cost," International Meeting on Radiation Processing, Avignon, France, March 2001.

Desrosiers, M.F., "The Next-Generation in Traceability: *e*-Calibrations," Measurement Sciences Conference, Anaheim, CA, January 2001.

Gentile, T.R., "The NIST-Indiana-Hamilton Polarized ^{3}He Neutron Spin Filter Program," Meeting of the European Neutron Polarization Initiative, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, United Kingdom, June 2001.

Gilliam, D.M., "NIST Neutron Physics and Dosimetry," 2000 American Nuclear Society/European Nuclear Society International Meeting, Washington, DC, November 2000.

Gilliam, D.M., "NIST and the National Program in Fundamental Neutron Physics," Workshop on Fundamental Physics with Neutrons at the SNS, Oak Ridge National Laboratory, Oak Ridge, TN, September 2001.

Huffman, P.R., "Prospects for an Improved Neutron Lifetime Measurement Using Magnetically Trapped Ultracold Neutrons," Physics Colloquium, North Carolina State University, Raleigh, NC, October 2000.

Huffman, P.R., "Magnetic Trapping of Ultracold Neutrons," Particle Physics Seminar, Brookhaven National Laboratory, Upton, NY, November 2000.

Huffman, P.R., "Neutron Lifetime via Trapped UCN," Workshop on Fundamental Neutron Physics at the Spallation Neutron Source (FNPSNS 2001), Oak Ridge, TN, September 2001.

Huffman, P.R., "Neutron Physics at NIST and ILL and Prospects for the SNS," Workshop on Fundamental Neutron Physics at the Spallation Neutron Source (FNPSNS 2001), Oak Ridge, TN, September 2001.

Inn, K.G.W., "Analytical Uncertainties," Quality Assurance Task Force of the Pacific Northwest Meeting, Seattle, WA, May 2001.

Inn, K.G.W., "A NIST Quality Assessment Program," CSRA-REMP Meeting, Charleston, SC, June 2001.

Jacobson, D.L., "Phase Contrast Imaging at NIST," Radiation Health Officer Seminar for the Armed Forces Radiobiology Research Institute, Bethesda, MD, April 2001.

Jacobson, D.L., "Neutron Phase Contrast Radiography," Fourth International Topical Meeting on Neutron Radiography, State College, PA, June 2001.

Lin, Z., "Competence of Alpha Spectrometry Algorithms Used to Resolve the ^{241}Am and ^{243}Am Alpha Perk Overlap," 13th International Conference on Radionuclide Metrology and Its Applications (ICRM2001), Braunschweig, Germany, May 2001.

Mitch, M.G., "Characterization of ^{103}Pd and ^{125}I Prostate Brachytherapy Seeds by Air-kerma Strength, X-ray Spectrometry, and Well-ionization Chamber Response Measurements," Mid-Atlantic Chapter of the American Association of Physicists in Medicine (AAPM) Annual Meeting, Georgetown Medical Center, Washington, DC, June 2001.

Nico, J.S., "Searching for Time Reversal Violation in Neutron Decay," Institut Laue-Langevin Seminar, Grenoble, France, April 2001.

Rich, D.R., "Progress in Optically Pumped ^{3}He Neutron Spin Filters," University of New Hampshire, Durham, NH, January 2001.

Rich, D.R., "Progress in Optically Pumped ^{3}He Neutron Spin Filters," University of Michigan, Ann Arbor, MI, May 2001.

Seltzer, S.M., "Evolution of Physical Standards for Exposure/Air Kerma," Annual Meeting of the American Association of Physicists in Medicine, Salt Lake City, UT, July 2001.

Soares, C.G., "How Accurate Can We Get?," Cardiovascular Radiation Therapy and Restenosis Forum, Washington, DC, February 2001.

Soares, C.G., "Update on the Determination of AAPM TG43/60 Parameters for Photon and Beta Sources," Cardiovascular Radiation Therapy and Restenosis Forum, Washington, DC, February 2001.

Soares, C.G., "Comparing Methods for Verifying Source Output at Clinical Sites," Meeting of the German Medical Physics Society Working Group 18, Vienna, Austria, March 2001.

Soares, C.G., "Calibration Procedures at NIST for Low-Energy Photon Sources and Beta-Particle Sources," Consultants' Meeting, International Atomic Energy Agency, Vienna, Austria, May 2001.

Soares, C.G., "Calibration of a Scintillator for Use in Beta-Particle Intravascular Brachytherapy Source Measurements," Annual Meeting of the American Association of Physicists in Medicine, Salt Lake City, UT, July 2001.

Soares, C.G., "National and International Standards and Calibration of Thermoluminescence Dosimetry Systems," 13th International Conference on Solid State Dosimetry, Athens, Greece, July 2001.

Wietfeldt, F.E., "A Backscattering-Suppressed Beta Spectrometer for Neutron Decay Experiments," Fall Meeting of the APS Division on Nuclear Physics, Williamsburg, VA, October 2000.

Wietfeldt, F.E., "Cold Neutron Decay Experiments at NIST," Nuclear Science Advisory Committee Long-Range Planning Meeting, Oakland, CA, November 2000.

Weitfeldt, F.E., "The Decay of the Neutron," Los Alamos National Laboratory Neutron Science Seminar, Los Alamos, NM, January 2001.

Wietfeldt, F.E., "The Parameters of Neutron Decay," University of Colorado at Boulder, Nuclear Physics Seminar, Boulder, CO, February 2001.

Wietfeldt, F.E., "Cold and Ultracold Neutrons," University of Colorado at Boulder, Physics Colloquium, Boulder, CO, February 2001.

Wietfeldt, F.E., "Studies of Neutron Decay at the NIST Center for Neutron Research," North Carolina State University, Nuclear Engineering Seminar, Raleigh, NC, May 2001.

Wietfeldt, F.E., "The Decay of the Neutron," National Institute of Standards and Technology, Physics Lab Colloquium, June 2001.

Zimmerman, B.E., "A Model for Analyzing Components of Uncertainty Encountered in ^{3}H-standard Efficiency Tracing in $4\pi\beta$ Liquid Scintillation Counting," with R. Collé, 2000 Meeting of the American Nuclear Society, Washington, DC, November 2000.

Zimmerman, B.E., "Recent Activities of the Nuclear Medicine Standards Program at NIST," National Laboratory for Ionizing Radiation Metrology, Institute for Radiation Protection and Dosimetry, Rio de Janeiro, Brazil, February 2001.

Zimmerman, B.E., "The Effect of Liquid Scintillation Cocktail Composition on Measurement Stability in the Assay of Solutions of ^{177}Lu," poster presented at LSC2001, Karlsruhe, Germany, May 2001.

Zimmerman, B.E., "The Standardization of ^{188}W/^{188}Re by $4\pi\beta$ Liquid Scintillation Spectrometry With the CIEMAT/NIST ^{3}H-Standard Efficiency Tracing Method," 13th International Conference on Radionuclide Metrology and Its Applications (ICRM2001), Braunschweig, Germany, May 2001.

TIME AND FREQUENCY DIVISION (847)

Bergquist, J.C., "SubdekaHz Optical Spectroscopy of 199Hg$^+$," SPIE Meeting, San Jose, CA January 2001.

Bergquist, J.C., "Optical Timepieces," DAMOP Conference, London, Ontario, Canada, May 2001.

Bergquist, J.C., "A Single Ion Optical Clock," ICOLS '01, Snowbird, UT, June 2001.

Bergquist, J.C., "A Single Atom Optical Clock," 6th Symposium on Frequency Standard and Metrology, St. Andrews, Scotland, September 2001.

Bergquist, J.C., "Clocks Using Quantum Entanglement," Zentrum for Moderne Optik, Erlangen, Germany, September 2001.

Bollinger, J.J., "Phase Transitions and Self-Organized Criticality in Laser-Cooled Crystallized Ion Plasmas," APS Meeting, Washington, D.C., April 2001.

Bollinger, J.J., "Quantum Information Processing in a Penning Ion Trap," Conference on Quantum Information, Rochester, NY, June 2001.

Bollinger, J.J. "A Laser-cooled Positron Plasma," 2001 Positron Workshop, Santa Fe, NM, July 2001.

Bollinger, J.J. "A Laser-cooled Positron Plasma," 2001 Workshop on Non-Neutral Plasmas, La Jolla, CA, July 2001.

Deutch, M., "NIST Time and Frequency Broadcast from Radio Stations WWVB, WWV, and WWVH," NCSL International Conference, Washington, DC, July 2001.

Diddams, S.D., "Absolute Frequency Measurements of Mercury and Calcium Laser-cooled Optical Frequency Standards," SPIE Meeting, San Jose, CA, January 2001.

Diddams, S.D., "Phase Control of Fs Lasers," University of New Mexico, Albuquerque, NM, March 2001.

Diddams, S.D., "Atomic Clocks in the Optical Domain," University of New Mexico, Albuquerque, NM, March 2001.

Diddams, S.D., "Frequency Measurements of Cold Atom Clocks," APS Conference, Washington, DC, April 2001.

Diddams, S.D., "Frequency Measurements of the Hg$^+$ and Ca Optical Standards with a Femtosecond-laser-based Optical Clockwork," 6th Symposium on Frequency Standards and Metrology, St. Andrews, Scotland, September 2001.

Drullinger, R.E., "All Optical Atomic Clocks," Frequency Control Symposium, Seattle, WA, June 2001.

Gifford, G.A., "GPS Time Transfer," United Nations Conference on Navigation and Timing, Kuala Lumpur, Malaysia, September 2001.

Heavner, T.P., "Preliminary Results from a Miniature Laser-cooled Cs Fountain Frequency Standard," 6th Symposium on Frequency Standard and Metrology, St. Andrews, Scotland, September 2001.

Hollberg, L.W., "Optical Clocks for the Future," SPIE Meeting, San Jose, CA, January 2001.

Hollberg, L.W., "Cold Atoms Plus Femtosecond Lasers for Optical Clocks," Yale University, New Haven, CT, April 2001.

Hollberg, L.W., "Optical Clocks for Space," Pan Pacific Basin Workshop, Pasadena, CA, May 2001.

Hollberg, L.W., "Cold-Atom Optical Clocks and Frequency Measurements," ICONO'01, Minsk, Belarus, June 2001.

Hollberg, L.W., "A Cold Ca Frequency Standard and Second Stage Cooling," ICOLS'01, Snowbird, UT, June 2001.

Hollberg, L.W., "Dawn of the Age of Optical Clocks: Fast Lasers and Cold Atoms," SPIE Meeting, San Jose, CA, July 2001.

Hollberg, L.W., "Laser-cooled Optical Clocks at NIST," 6th Symposium on Frequency Standards and Metrology, St. Andrews, Scotland, September 2001.

Howe, D.A., "100 GHz NIST Phase Noise Test Bed," ONR Superconducting Electronics Program Review, Sedona, AZ, February 2001.

Howe, D.A., "Properties of Stable Frequency Sources," Frequency Control Symposium, Seattle, WA, June 2001.

Jefferts, S.R., "Laser-cooled Cesium Clocks at NIST," American Physical Society Meeting, Seattle, WA, February 2001.

Jefferts, S.R., "NIST F-1, Recent Evaluations," 15th European Frequency and Time Forum, Neuchatel, Switzerland, February 2001.

Jefferts, S.R., "Spin Exchange Shift in Cs Fountains," 6th Symposium on Frequency Standards and Metrology, St. Andrews, Scotland, September 2001.

Kielpinski, D.F., "Recent Results in Trapped Ion Quantum Computing," International Conference on Experimental Implementations of Quantum Computation, Sydney, Australia, January 2001.

Kielpinski, D.F., "Recent Results in Trapped Ion Quantum Computing," Quantum Information Workshop, Coolangatta, Australia, January 2001.

Kielpinski, D.F., "A Decoherence-Free Quantum Memory Using Trapped Ions," DAMOP, London, Canada, May 2001.

Kitching, J.E., "Toward an Atomic Clock on a Chip: Miniaturization of Frequency References," DAMOP Conference, London, Ontario, Canada, May 2001.

Kitching, J.E., "Spectroscopic Line Shifts from Frequency-Dependant Optical Pumping in Driven, Three Level Systems," ICOLS '01, Snowbird, UT, June 2001.

Kitching, J.E., "A Compact Microwave Frequency Reference Based on Coherent Population Trapping Resonances in Cs Vapor," 6th Symp. on Frequency Standards and Metrology, St. Andrews, Scotland, September 2001.

Kriesel, J.M., "Laser Induced Wakes in Ion Crystals," University of California at San Diego, San Diego, CA, January 2001.

Kriesel, J.M., "Laser Induced Wakes in Ion Crystals," University of California at San Diego, San Diego, CA, July 2001.

Levine, J., "Carrier Phase GPS Over a Transatlantic Baseline," Frequency Control Symposium, Seattle, WA, June 2001.

Levine, J., "Legal Traceability of Time," National Conference of Standards Laboratories, Washington, DC, July 2001.

Lombardi, M.A., "Time and Frequency Measurements Using the Global Positioning System," Measurement Science Conference, Anaheim, CA, January 2001.

Lowe, J.P., "NIS/NIST Time and Frequency Dissemination by Satellite," National Conference of Standards Laboratories, Washington, DC, July 2001.

Meyer, V., "Experiments with Two Entangled Beryllium Ions," Cohevol Workshop, Dresden, Germany, May 2001.

Meyer, V., "Trapped Ion Entanglement for Precision Measurement and Decoherence Suppression," ICQL '01 Conference, Rochester, New York, June 2001.

Meyer, V., "Experiments with Two Entangled Beryllium Ions," 2001 International Symposium on Quantum Information, Huangshan, China, September 2001

Nelson, L.M., "Report from NIST," CGSIC Meeting, Crystal City, VA, March 2001.

Nelson, L.M., "Understanding Limitations of GPS Carrier Phase Frequency Transfer on a Transatlantic Baseline," IEEE Frequency Control Symposium, Seattle, WA, June 2001.

Nelson, L.M., "Report from NIST," CGSIC Meeting, Salt Lake City, UT, September 2001.

Oates, C.W., "Absolute Frequency Measurement of the 657nm Intercombination Line in Neutral ^{40}Ca," CLEO/QELS 2001 Conference, Baltimore, MD, May 2001.

Oates, C.W., "A Ca Optical Frequency Standard at 657nm: Improvements and Frequency Measurements," 6th Symposium on Frequency Standards and Metrology, St. Andrews, Scotland, September 2001.

Parker, T.E., Introduction to Time and Frequency Transfers," Frequency Control Symposium, Seattle, WA, June 2001.

Parker, T.E., "First Comparison of Remote Frequency Standards," Frequency Control Symposium, Seattle, WA, June 2001.

Parker, T.E., "Comparing High Performance Frequency Standards," 6th Symposium on Frequency Standards and Metrology, St. Andrews, Scotland, September 2001.

Peppler, T.K., "Definitions of Total Estimators of Common Time-Domain Variances," Frequency Control Symposium, Seattle, WA, June 2001.

Rowe, M.A., "Experimental Violation of Bell's Inequalities with Efficient Detection," Thirty First Winter Colloquium on the Physics of Quantum Electronics, Snowbird, UT, January 2001.

Rowe, M.A., "Ion Entanglement Experiments at NIST," Southwest Quantum Information and Technology Network Annual Meeting, Pasadena, CA, March, 2001.

Rowe, M.A., "Ion Entanglement for Fundamental Tests and Precision Measurements," DAMOP Conference, London, Ontario, Canada, May 2001.

Rowe, M.A., "Ion Entanglement Experiments at NIST," Exploring Quantum Physics Conference, Venice, Italy, August 2001.

Rowe, M.A., "Ion Entanglement Experiments at NIST," Mysteries in Quantum Measurements Workshop, Gargnano, Italy, August 2001.

Sullivan, D.B., "Frequency Standards at NIST," International Microwave Symposium, Phoenix, AZ, May 2001.

Sullivan, D.B., "Time and Frequency Measurements at NIST: The First 100 Years," Frequency Control Symposium, Seattle, WA, June 2001.

Sullivan, D.B., "PARCS: A Laser-cooled Atomic Clock in Space," 6th Symposium on Frequency Standard and Metrology, St. Andrews, Scotland, September 2001.

Weiss, M.A., "T1X1 Input to GPS3," T1X1.3 Meeting, Orlando, FL, June 2001.

Weiss, M.A., "Information on NTIA Report 01-384," T1X1.3 Meeting, Orlando, FL, June 2001.

Weiss, M.A., Precise Time and Frequency Using WAAS and EGNOS Satellites with High-Gain Antennas," 6th Symposium on Frequency Standard and Metrology, St. Andrews, Scotland, September 2001.

Wineland, D.J., "Quantum Computation, Entangled Atoms and Schrödinger's Cat," American Association for the Advancement of Science Annual Meeting, San Francisco, CA, February 2001.

Wineland, D.J., "Elements of Quantum Computation with Trapped Atomic Ions," International School of Physics "Enrico Fermi; Course on Quantum Computation and Information," Lake Como, Italy, July 2001.

Wineland, D.J., "Entanglement Methods in Ion Traps," International School of Physics "Enrico Fermi; Course on Quantum Computation and Information," Lake Como, Italy, July 2001.

Wineland, D.J., "Applications of Entanglement for Precision Measurement," International School of Physics "Enrico Fermi; Course on Quantum Computation and Information," Lake Como, Italy, July 2001.

Wineland, D.J., "Entanglement-enhanced Precision Measurement," 2001 Workshop on Laser Physics and Quantum Optics, Jackson Hole, WY, August 2001.

Wineland, D.J., "Trapped-Ion Quantum Computing," NSA/ARDA Quantum Computing Program Review, Baltimore, MD, August 2001.

QUANTUM PHYSICS DIVISION (848)

Cornell, E.A., "The Low-Temperature Magnifying Glass: Bose-Einstein Condensation and the Visible Machinery of Quantum Mechanics," University of Arizona, Tucson, AZ, February 2001.

Cornell, E.A., "The Low-Temperature Magnifying Glass: Bose-Einstein Condensation and the Visible Machinery of Quantum Mechanics," York University, Toronto Canada, March 2001.

Cornell, E.A., "The Low-Temperature Magnifying Glass: Bose-Einstein Condensation and the Visible Machinery of Quantum Mechanics," University of Michigan, Ann Arbor, MI, March 2001.

Cornell, E.A., "The Story of Laser Cooling and BEC at NBS/NIST," APS Annual Meeting, Washington, DC, April 2001.

Cornell, E.A., "The Low-Temperature Magnifying Glass: Bose-Einstein Condensation and the Visible Machinery of Quantum Mechanics," University of Colorado, Boulder, CO, April 2001.

Cornell, E.A., "Rotating Bose-Einstein Condensates," CLEO/QELS, Baltimore, MD, May 2001.

Cornell, E.A., "Coherence and Decoherence in Magnetically Trapped Ultra-Cold Rubidium-87," Eighth Rochester Conference on Quantum Optics (CQO8), Rochester, NY, June 2001.

Cornell, E.A., "Vortices from Rotating Clouds," Gordon Conference on Atomic Physics, Williamstown, MA, June 2001.

Cornell, E.A., "Coherence and Decoherence in Condensed and Noncondensed Ultracold Atoms,' Enrico Fermi Summer School, Varenna, Italy, July 2001.

Cornell, E.A., "The Ultra-Low Temperature Magnifying Glass: How Bose-Einstein Condensation Makes Quantum Mechanics Visible," SPIE, San Diego, CA, August 2001.

Cornell, E.A., "Bose-Einstein Condensation Experiments at JILA," European Research Conference on Bose-Einstein Condensation, San Feliu de Guixols, Spain, September 2001.

Cundiff, S.T., "Interaction effects in optically dense material," SPIE Photonics West, San Jose, CA, January 2001.

Cundiff, S.T., "Carrier envelope phase control of modelocked lasers," SPIE Photonics West, San Jose, CA, January 2001.

Cundiff, S.T., "Carrier-Envelope Phase Control of Femtosecond Modelocked Lasers and Direct Optical Frequency Synthesis," University of Michigan, Ann Arbor, MI, February 2001.

Cundiff, S.T., "Carrier-Envelope Phase Control of Femtosecond Modelocked Lasers and Direct Optical Frequency Synthesis," Conference on. Laser Electrooptics, Baltimore, MD, May 2001.

Cundiff, S.T., "Optical Frequency Metrology with Modelocked Lasers," Femtosecond Technology workshop, Tskuba, Japan, June 2001.

Cundiff, S.T., "Carrier-Envelope Phase Control of Femtosecond Modelocked Lasers and Direct Optical Frequency Synthesis," University of Tokyo, Japan, June 2001.

Cundiff, S.T., "Phase Stabilization of Modelocked Lasers," Nonlinear Optics Gordon Research Conference, July 2001.

Cundiff, S.T., "Local Field Effects in a Dense Atomic Vapor," Alaska Meeting on Fundamental Optical Processes in Semiconductors, August 2001.

Faller, J.E., "Design of New Cam-Driven Gravimeter and Thoughts on Dropping Atoms," New Technologies for Absolute Gravimetry at BIPM, Severes, France, February 2001.

Faller, J.E., "Precision Measurements with Gravity," University of San Francisco, San Francisco, CA, February 2001.

Faller, J.E., "NIST Centennial Celebration and Keithley Award Session," American Physical Society, Seattle, WA, March 2001.

Faller, J.E., "Physics of Music," University of Colorado Wizards Program, Boulder, CO, March 2001.

Faller, J.E., "The Current State of Absolute Gravimetry," D.I. Mendeleyev Institute for Metrology (VNIIM), St. Petersburg, Russia, June 2001.

Faller, J.E., "Prospects for a Truly Portable Absolute Gravimeter," International Association of Geodesy, Helsinki, Finland, August 2001.

Faller, J.E., "The Current State of and Future Prospects for Absolute Gravimetry," International Association of Geodesy, Budapest, Hungary, September 2001.

Hall, J.L., "Along the Highway to Optical Clocks: an Overview," American Physical Society Annual meeting, Washington DC, April 2001.

Hall, J.L., "Coherent Optical Frequency Synthesis and Distribution," International Conference on Laser Spectroscopy, Snow Bird, UT, June 2001.

Hall, J.L, "Overview of the Femtosecond Comb Approach to Optical Frequency Measurement," BIPM Comité Consultatif de Longeur, Sévres (Paris) France, September 2001.

Hall, J.L., "From Stabilized Lasers to Optical frequency Standards," The Sixth Intl. Symposium on Frequency Standards and Metrology, St Andrews, Fife, Scotland, September 2001.

Jin, D.S., "Exploring a Quantum Degenerative Fermi Gas of Atoms," Quantum Optics IX, Malorca, Spain, October 2000.

Jin, D.S., "A Two-Component Fermi Gas of Atoms," APS Atomic, Molecular, and Optical Physics Meeting, London, Ontario, May 2001.

Jin, D.S., "A Two-Component Fermi Gas of Atoms," XXII International Conference on Photonic, Electronic, and Atomic Collisions, Santa Fe, NM, July 2001.

Leone, S.R., "Ultrafast laser photoionization: Coherent control dynamics and time-resolved x-ray photoelectron spectroscopy, "Argonne National Laboratory, Argonne, IL, February 2001.

Leone, S.R., "Ultrafast laser studies of coherent control, evolutionary algorithms, and x-ray photoelectron dynamics," The James Franck Institute, University of Chicago, Chicago, IL, February 2001.

Leone, S.R., "Ultrafast laser studies of coherent control, evolutionary algorithms, and x-ray photoelectron dynamics," Harvard/MIT Seminar, Cambridge, MA, March 2001.

Leone, S.R., "Ultrafast soft x-ray femtosecond photoelectron spectroscopy," The University of Tokyo, Tokyo, Japan, March 2001.

Leone, S.R., "Femtosecond soft x-ray time-resolved photoelectron spectroscopy," American Chemical Society National Meeting, San Diego, CA, April 2001.

Leone, S.R., "Ultrafast molecular wave packet dynamics with triple resonance detail," Intl. Conference, Spectroscopy in the 21st Century, Tokyo, Japan, March 2001.

Leone, S.R., "Femtosecond time-resolved soft x-ray photoelectron spectroscopy," Gordon Research Conference, Williams College, Williamstown, MA, July 2001.

Leone, S.R., "Wave packet phase control, evolutionary algorithms, and quantum information," Gordon Research Conference, Mt. Holyoke College, South Hadley, MA, July 2001.

Nesbitt, D.J., "Laser/FTIR Slit Jet Studies of Hydrogen Bonded Clusters," Optical Society of America –Interdisciplinary Laser Science National Meeting, Providence, RI, October 2000.

Nesbitt, D.J., "Chemical Physics at the Single Molecule Level: From Quantum Dots to Biomolecules," National Institute for Standards and Technology, Gaithersburg, MD, November 2000.

Nesbitt, D.J., "Dynamics from Single Collisions to Single Molecules," California Institute of Technology, Pasadena, CA, January 2001.

Nesbitt, D.J., "From Single Collisions to Single Molecules," Stanford University, Palo Alto, CA, February 2001.

Nesbitt, D.J., "Chemical Physics: One Molecule at a Time," JILA Colloquium Series, University of Colorado, Boulder, CO, April 2001.

Nesbitt, D.J., "High Resolution IR Studies of Hydrogen Bonded Clusters: Large Amplitude Dynamics in $(HCl)_n$," Faraday Discussion, University of Durham, Durham, UK, April 2001.

Nesbitt, D.J., "Photoluminescence Kinetics and Dynamics in Semiconductor Nanocrystals," CLEO/QELS 2001, Baltimore, MD, May 2001.

Nesbitt, D.J., "IR Laser Studies of Radicals: From Spectroscopy to Dynamics," 26th Intl. Symposium on Free Radicals, Assisi, Italy, September 2001.

Nesbitt, D.J., "Chemistry of Cooking," University of Colorado, Boulder, CO, September 2001.

Ye, J., "Optical atomic clock and frequency synthesizers," "Ultrasensitive laser spectroscopy and its applications to fundamental physics," "Trapping and tracking of single atoms and real time quantum dynamics," Bai-Yu-Lan Lecture Series, (1) East China Normal University, (2) Jiao Tong University, and (3) FuDan University, Shanghai, China, December 2000.

Ye, J., "Ultrasensitive laser spectroscopy, Optical atomic clock and optical frequency synthesizers," General physics seminar, FOM Institute for Plasma Physics 'Rijnhuizen' and University of Nijmegen, Netherlands, December 2000.

Ye, J., "Sub 10-femtosecond synchronization and carrier phase locking of two passively mode-locked Ti:sapphire oscillators," The 31st Winter Colloquium on the Physics of Quantum Electronics, Snowbird, Utah, January 2001.

Ye, J., "Precision phase control of femtosecond lasers: optical atomic clocks, optical frequency synthesizers, and optical waveform synthesis," Physics Seminar, Stanford University, Palo Alto, California, March 2001.

Ye, J., "Precision phase control of femtosecond lasers: from optical frequency synthesizer to quantum dynamics," Physics Seminar, University of California at Berkeley, Berkeley, California, March 2001.

Ye, J. "Phase Stabilized Femtosecond Laser Combs: From Optical Frequency Synthesizer to Quantum Dynamics," American Physical Society Annual meeting, Washington DC, April 2001.

Ye, J., "Optical atomic clock and coherent optical waveform synthesis," The 15th Intl. Conference on Laser Spectroscopy (ICOLS-XV), Snowbird, Utah, June 2001.

Ye, J., "Coherent synthesis of optical frequencies and waveforms," 2001 Atomic Physics Gordon Research Conf., Williamstown, Massachusetts, June 2001.

Ye, J., "Coherent pulse synthesis from separate ultrafast lasers," Ultrafast Optics III, Château Montebello, Québec, Canada, July 2001.

Ye, J., "Coherent frequency synthesis and pulse waveform generation in the optical spectrum," The 2001 Workshop on Laser Physics and Quantum Optics, Jackson Hole, Wyoming, July 2001. ❑

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

LABORATORY OFFICE

Robert Dragoset

Member, NIST Information Coordinators

Member, NIST Web Designers Group, Subgroup of the NIST Information Coordinators

Member, NIST Museum Committee

Member, NIST 508 Accessibility Team

Katharine Gebbie

Vice Chair, American Physical Society Selection Committee for the Hans A. Bethe Prize.

Member, Advisory Committee, American Institute of Physics.

Interagency Award Committee for the Enrico Fermi Award.

Member, American Physical Society Physics Planning Committee.

Member, International Union of Pure and Applied Physicists Working Group on Women in Physics.

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

William R. Ott

NIST Liaison, SDI/BMDO Metrology Projects at NIST.

Member, Program Committee, SPIE Symposium on Harnessing Light: Optical Science and Metrology at NIST, July 2001.

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

Member, NIST Small Business Innovative Research Selection Committee.

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

Chairman, NIST Colloquium Series for Distinguished Speakers.

Barry N. Taylor

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

Chairman, WG 1, Expression of Uncertainty in Measurement, of the Joint Committee for Guides on Metrology (JCGM).

Member, JCGM/WG 2, Basic and General Terms in Metrology.

Member, ISO Technical Committee 12, Quantities, Units, Symbols, Conversion Factors.

Member, CODATA Task Group on Fundamental Constants.

Vice-Chair, IEEE Standards Coordinating Committee 14, Quantities, Units, and Letter symbols.

ELECTRON & OPTICAL PHYSICS DIVISION (841)

Robert J. Celotta

Chair, Gordon Research Conference on Magnetic Nanostructures.

Member, Executive Committee, Group on Instrument and Measurement Science, American Physical Society.

Member, Committee on Implications of Emerging Micro and Nano Technologies, National Research Council Study Committee 2001-2002.

Charles W. Clark

Chair, Physics Panel II, U.S. Civilian Research and Development Foundation.

NIST Centennial Liaison with American Physical Society.

Member, Advisory Board, Harvard-Smithsonian Institute for Theoretical and Atomic Physics.

Member, Program Committee, March Meeting of the American Physical Society.

Charles W. Clark (cont'd)

Member, Annual Program Committee Meeting, American Association for the Advancement of Science.

Member, Peer Review Rapid Action Committee, Optical Society of America.

Panelist, National Science Foundation Workshop on Computational Physics.

NIST Representative in Joint Atomic, Molecular and Optical Science Program with University of Maryland.

Adjunct Professor, University of Maryland.

Physics Laboratory representative, NIST Information Technology Strategy Planning Team.

Zachary H. Levine

Chair, Scientific Computing Working Group, NIST Information Technology Strategic Planning Team.

Member, Computational Material Science Network.

Thomas B. Lucatorto

NIST Centennial Liaison with Optical Society of America.

Member, review panel to evaluate proposals submitted to the New York Scientific, Technical and Academic Research (NYSTAR) Program.

Jabez McClelland

Member, National Science Foundation Nanotechnology Review Panel.

Daniel T. Pierce

Chair, International Organizing Committee, International Colloquium on Magnetic Films and Surfaces.

Member, Executive Committee, Division of Materials Physics, American Physical Society.

Member, Spintronics 2001, Scientific Advisory Committee.

Mark Stiles

Member, Organizing Committee, Spintronics 2001: Novel Aspects of Spin-.Polarized Transport and Spin Dynamics.

Charles Tarrio

Member, Advisory Board, Extreme Ultraviolet Lithography Limited Liability Corporation.

John Unguris

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

ATOMIC PHYSICS DIVISION (842)

Garnett W. Bryant

Program Committee for Nano-optics at CLEO/QELS2001 and CLEO/QELS2002.

John H. Burnett

Chair, Metrology Session for the Second International Symposium on 157 nm Lithography, San Diego, California, May 2001.

Richard D. Deslattes

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

Member, 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.

Chair, American Physical Society Topical Group on Precision Measurement and Fundamental Constants.

Jeffrey R. Fuhr

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

John D. Gillaspy

Member, International Advisory Board, Nanologic, Inc. Working Group

Co-chair, Program Committee, International Workshop on New Ions for Micro- and Nanoelectronics (NIM 2003, Paris).

Yong-Ki Kim

Member, Program Committee, Conference on "Atomic Processes in Plasmas," to be held in Gatlinburg, TN, April 2002.

Paul D. Lett

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

William C. Martin

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

Peter J. Mohr

Chair, CODATA Task Group on Fundamental Constants.

Chair, Precision Measurement and Fundamental Constants Topical Group of the APS.

Member, U.S. National CODATA Committee.

Physics Laboratory representative on the International Comparisons Database Project

IUPAP Liaison to CODATA

Gillian Nave

Vice-Chair of Working group I "Atomic Spectra and Wavelengths" of Commission 14 "Atomic and Molecular data" of the International Astronomical Union.

William D. Phillips

Co-Chair, Cargese Summer School on Coherent Atom Optics.

Member, National Academy of Science Committee to update the report on the Future of Atomic Molecular and Optical Science (FAMOS).

Member, National Academy of Sciences Committee on Women in Science and Engineering.

Joseph Reader

Member, Program Committee, 7th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, 2001.

Steven L. Rolston

Chair, 2001 Atomic Physics Gordon Research Conference, Plymouth, NH.

Edward B. Saloman

Member, Library Advisory Committee, Optical Society of America.

Jason Sanabia

Summer Undergraduate Research Fellow Selection Committee - NIST.

Craig J. Sansonetti

Member, Technical Program Committee, Fourier Transform Spectroscopy Topical Meeting, Optical Society of America, Coeur d'Alene, ID.

Wolfgang L. Wiese

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

Member, Program Committee, 7th and 8th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, 2001 and 2004.

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, 3rd International Conference on Atomic and Molecular Data and Their Applications (ICAMDATA), Oak Ridge, TN, 2002.

Carl J. Williams

Secretary of Theoretical Atomic, Molecular, And Optical Committee (TAMOC).

OPTICAL TECHNOLOGY DIVISION (844)

Sally Bruce

Member, CORM (Council on Optical Radiation Measurement).

Member, International Conference of Standards Laboratories (NCSL), International liaison delegate from CORM.

Member, American Society of Quality (ASQ), Measurement Quality Division.

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.

Edward Early

Member, Council for Optical Radiation Measurements.

Member, ASTM Committee E12 on Color and Appearance.

Member, PIMA Subcommittee IT2-28 on Densitometry.

Member, CIE TC 2-39 on Geometric Tolerances for Color Measurement.

Member, CIE TC-2-36 on Retroreflection: Definition and Measurement.

George Eppeldauer

NIST Representative to the CIE/USA National Committee of the CIE.

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 2-29 Measurement of Detector Linearity.

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

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, CORM (Council for Optical Radiation Measurements).

Coordinator for the CCPR Aperture Area Intercomparison.

Thomas Germer

Member, ASTM Committee E12 on Color and Appearance.

Member, ASTM Committee F1 on Electronics.

Member, ASTM Committee F1.06 on Silicon Materials and Process Control.

Charles Gibson

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

Member, CORM.

Leonard Hanssen

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

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

Member, SPIE Working Group on Optical Materials and Optics Fabrication.

Member, ISO/TC 172/SC 3/WG 3 Working Group for Characterization of IR Materials.

Jonathan Hardis

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, CIE TC 2-42 Colormetric Measurements for Visual Displays.

Representative, Optics & Electro-Optics Standards Council.

Participant, Optoelectronics Industry Development Association (OIDA) Roadmapping Activities.

Edwin Heilweil

Member, Membership Committee, NIST Sigma XI Chapter.

Member, Steering Committee, NIST Combinatorial Methods Working Group.

Member, Technical Organizing Committee for Time-Resolved Vibrational Spectroscopy International Conferences.

Angela Hight Walker

Chairperson, Membership Committee, NIST Chapter of Sigma Xi.

Member, Steering Committee, NIST Combinatorial Methods Working Group.

Angela Hight Walker (Cont'd)

NIST Representative, Awards Committee, PECASE.

Physics Laboratory representative, NIST Centennial Professional Societies Subcommittee.

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.

Jeeseong Hwang

Member, NIST Working Group on Measurements and Materials at the Bio-Interface.

Marilyn Jacox

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

B. Carol Johnson

Member, ASTM Subcommittee E20.02 on Radiation Thermometry.

Member, NASA/EOS Calibration Panel.

Member, CORM.

Member, American Society for Testing and Materials.

Simon G. Kaplan

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

Member, SPIE Technical Group on Optical Properties of Materials.

Member, SPIE Technical Group on Polarization.

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.

Keith Lykke

Chairman, International Advisory Committee for NEWRAD.

Participant, OIDA Roadmapping Activities.

Member, CORM.

Alan L. Migdall

Member, Council for Optical Radiation Measurements (CORM).

Consultant with EuroMet coordinating committee on correlated photon metrology.

Member, Subcommittee on Quantum Optics for Quantum Electronic and Laser Conference.

Member, Smithsonian National Academy of Sciences, Physics Curriculum Evaluation Panel.

Maria Nadal

Chairman, ASTM Subcommittee E12.93 on Precision and Bias.

Member, ASTM Subcommittee E12.02 on Spectrophotometry and Colorimetry.

Member, ASTM Subcommittee E12.03 on Geometry.

Member, ASTM Subcommittee E12-12 on Metallic and Pearlescent Colors.

Member, ASTM Subcommittee E12-14 on Multi-Dimensional Characterization of Appearance.

Yoshi Ohno

Chairman, ASTM E12.11 WG05 Flashing Lights.

Chairman, IEC TC100/TA2 Color Management and Measurement of Multimedia Systems.

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

Chairman, CIE TC2-49 Photometry of Flashing Lights.

Chairman, CORM Subcommittee CR-3 on Photometry.

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

Member, IESNA Testing Procedures Committee.

Yoshi Ohno (Cont'd)

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

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 TC2-46 CIE/ISO Standards on LED Intensity Measurements.

Member, CORM CR4 Integrating Devices.

Member, CORM CR5 Electronic Displays.

Delegate to Lamp Testing Engineers Conference (LTEC).

Member, SAE AE-8D Wire and Cables, Task Group for Wire Contrast.

Albert Parr

Member, CIE.

NIST Representative, CCPR.

NIST Representative, CCPR Air UV Working Group.

Ex Officio Member, NIST Liaison, CORM Board of Directors.

Delegate, National Conference of Standards Laboratories (NCSL).

Member, International Advisory Committee for NEWRAD.

Robert Saunders

Member, ANSI Z311, Photobiological Safety of Lamps and Lighting Systems.

Alternate, ASTM E-20, Temperature Measurements.

Member, USDA Steering Committee for UV-B Measurements.

Alternate, ASTM E-44, Solar Energy Conversion.

Member, USNC/CIE.

Member, ASTM Subcommittee E20.2 Radiation Thermometry.

Member, CCPR Air UV Working Group.

Member, CORM Radiometry Subcommittee CR-1 on Radiometric Lamp Availability.

Eric Shirley

Member, CORM Subcommittee OP5 on Infrared Optical Properties of Materials.

Member, International Advisory Board for the 14^{th} International Conference on Vacuum Ultraviolet Radiation Physics (Austrailia 2004).

Benjamin Tsai

Member, ASTM E07 Committee on Nondestructive Testing.

Member, ASTM Committee E-21 on Space Simulation and Applications of Space Technology.

Howard Yoon

Member of the CR-1 Committee of CORM.

Member, Advisory Committee for Middle School Science Project, Smithsonian Institution and the National Academy of Sciences.

IONIZING RADIATION DIVISION (846)

James M. Adams

Chairman, American Society for Testing and Materials (ASTM) Task Group E10.05.05 on Activation Reactions.

Secretary, ASTM Symposium Committee and Program Committee for the Eleventh International Symposium on Reactor Dosimetry.

Secretary, ASTM Subcommittee E10.05 on Nuclear Radiation Metrology.

Member, ASTM Committee E10 on Nuclear Technology and Applications.

Member, American Nuclear Society (ANS) Committee ANS-19.10 on Fast Neutron Fluence to Pressurized Water Reactors.

James M. Adams (cont'd)

Member, Council on Ionizing Radiation Measurements and Standards (CIRMS), Subcommittee on Industrial Applications and Materials Effects.

Member, Program Committee, Harnessing Light: Optical Science and Metrology at NIST, SPIE International Symposium on Optical Science and Technology.

Muhammad Arif

Chairman, NIST Research Advisory Committee (RAC).

Paul M. Bergstrom

Session Chair, International Conference on the Application of Accelerators in Research and Industry.

Allan D. Carlson

Chairman, Consultants' Meetings of the International Atomic Energy Agency on Improvement of the Standard Cross Sections for Light Elements

Member, Cross Section Evaluation Working Group (CSEWG), National Nuclear Data Center.

Member, Evaluation Committee of CSEWG.

Member, Measurements Committee of CSEWG

Member, Coordinating Committee of the U.S. Department of Energy (DoE) Nuclear Data Program.

Coordinator, Subgroup on Evaluation of the Nuclear Data Standards of the Working Party on International Evaluation Cooperation of the NEANSC.

Member, International Technical Program Committee for the International Conference on Nuclear Data for Science and Technology to be held in Japan, October 2001.

Jeffrey T. Cessna

Member, International Committee for Radionuclide Metrology (ICRM) Life Sciences Working Group.

Member, ICRM Liquid Scintillation Committee Working Group.

Member, European Association of Nuclear Medicine.

Alternate, NIST Ionizing Radiation Safety Review Subcommittee.

Member, CIRMS Medical Subcommittee.

Ronald Collé

Member, Interagency Committee on Indoor Air Quality (CIAQ), Radon Workgroup.

Editorial Board, NIST Journal of Research Member, Interagency Committee on Indoor Air Quality (CIAQ), Radon Workgroup.

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.

Member, IEEE Conference Policy Committee of the Nuclear and Plasma Sciences Society Administrative Committee.

Member, U.S. National Committee of the International Electrotechnical Commission (IEC).

Chief U.S. Delegate, IEC Committee TC45, Nuclear Instrumentation.

Technical Advisor, U.S. National Committee for IEC Committee TC45, Nuclear Instrumentation.

Member, IEC Committee TC45 Working Group 1, Nomenclature.

Member, IEC Committee TC45 Working Group 3, Interchangeability.

Member, IEC Committee TC45 Working Group 9, Detectors.

Technical Advisor, U.S. National Committee for IEC Subcommittee SC45B, Radiation Protection Instrumentation.

Bert M. Coursey

Consultant, Radiation Therapy Committee of American Association of Physicists in Medicine (AAPM).

President, NIST Chapter Sigma Xi, the Scientific Research Society.

Bert M. Coursey (Cont'd)

Member, Low-energy Interstitial Brachytherapy Dosimetry Subcommittee of Radiation Therapy Committee, AAPM.

Member, Accredited Dosimetry Calibration Laboratory Subcommittee of Radiation Therapy Committee, AAPM.

Member ANSI Subcommittee N42.2 "ANSI Standards for Nuclear Radiation Detectors."

NIST Representative, CIRMS.

DOC Delegate, 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, CIRMS, Radiation Effects Subcommittee.

Member, ASTM Committee E10, Dosimetry.

David M. Gilliam

Member, ASTM Subcommittee E10.05, Nuclear Radiation Metrology.

Chair, ASTM Task Group E10.05.10, Neutron Metrology.

Member, Symposium Committee, ASTM-EURATOM Symposium Committee on Reactor Dosimetry.

NIST Representative, CCRI, Section III Mesures Neutroniques.

Recording Secretary, International Nuclear Target Development Society.

Member, Program Advisory Committee, North Carolina State University Reactor Facility.

Kenneth Inn

Member, ASTM Nuclear Fuel Cycle Committee, Environmental Test Methods, C26.05.01.

Member, ASTM Water, Radioactivity Test Methods, D19.

Member, CIRMS, Sub-committee on Environmental/Public Radiation Protection.

Member, Multi-Agency Radiological Laboratory Procedures (MARLAP).

Lisa R. Karam

Member, ICRM Scientific Program Committee.

Member, CIRMS Medical Subcommittee.

Member, CIRMS Public and Environmental Radiation Protection Subcommittee.

Member, NIST Institutional Review Board (IRB).

NIST Representative, CCRI section 2 (Radioactivity Measurements).

Paul J. Lamperti

Consultant, AAPM Radiation Committee.

Jeffrey S. Nico

Member, NIST Radiation Safety Subcommittee.

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.

Stephen M. Seltzer

Member, International Commission on Radiation Units and Measurements (ICRU).

Member, ICRU Committee on Fundamental Quantities and Units.

Sponsor, ICRU Report Committee on Dosimetry Systems for Radiation Processing.

Sponsor, ICRU Report Committee on Elastic Scattering of Electrons and Positrons.

Chairman, ICRU Advisory Group on Atomic and Nuclear Data.

Member, National Council on Radiation Protection and Measurements (NCRP).

Member, Radiation Therapy Committee Task Group on Kilovoltage X-Ray Beam Dosimetry, American Association of Physicists in Medicine (AAPM).

Member, CIRMS Subcommittee Medical Applications.

U.S. Delegate, IAEA Advisory Group on the Evaluation of and Recommendations on the Dosimetry Programme.

Jileen Shobe

Member, Laboratory Accreditation Assessment Committee, Health Physics Society.

CIRMS Representative, Health Physics Society, ANSI N13 Parent Committee.

Member, CIRMS Subcommittee on Medical Applications.

Member, CIRMS Subcommittee on Operational Radiation Protection.

Christopher G. Soares

Member, IAEA report committee, "Calibration of Beta-Ray and Low-Energy Photon Sources for Brachytherapy."

Member, IAEA report committee, "Calibration of Brachytherapy Sources."

U.S. 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, AAPM Subcommittee, Intravascular Brachytherapy.

Member, ICRU Report Committee, "Beta Rays for Therapeutic Applications."

Member, Data Safety Monitoring Committee, Washington Hospital Center.

Member, Health Physics Society (HPS), Scientific Subcommittee Work Group for the revision of ANSI N13.11, "Personnel Dosimetry Performance–Criteria for Testing."

Member, Health Physics Society (HPS), 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."

Julian H. Sparrow

Chairperson, JANNAF Nondestructive Evaluation subcommittee panel, "Acceptance and NDE Standards."

Alan K. Thompson

Member, ANSI N13-38, Standards for Neutron Personnel Protection Meters.

Member, Bohmische Physical Society.

Member, ISO Technical Committee 85, Subcommittee 2, Working Group 2 (Reference Radiations).

Michael P. Unterweger

Member and Co-Chairman, ICRM Radionuclide Metrology Techniques Working Group

Member, ASTM D022 Committee on Sampling and Analysis of Atmospheres.

Member, IEEE NIM/FASTBUS Committee.

Member, IEEE Nuclear Instruments and Detectors Committee.

Member, IEEE Nuclear and Plasma Sciences Society (NPSS) Administrative Committee.

Member, ANSI N42.2, Radioactivity Measurements.

Convener and Assistant Technical Advisor for TC/45/WG9 IEC Committee.

Brian E. Zimmerman

Member, ANSI Standard N42.13 ,"Calibration and Usage of 'Dose Calibrator' Ionization Chambers for the Assay of Radionuclides."

Member, CIRMS Medical Subcommittee.

Coordinator, Life Sciences Working Group, ICRM.

Member, NIST Ionizing Radiation Safety Review Subcommittee

TIME AND FREQUENCY DIVISION (847)

J.C. Bergquist

Member, International Steering Committee for the Sixth Symposium on Frequency Standards and Metrology.

Member, NIST Precision Measurement Grants Committee.

John J. Bollinger

Member, International Advisory Board, Conference on Strongly Coupled Coulomb Systems.

Member, Organizing Committee, 2001 Workshop on Non-Neutral Plasmas.

Robert E. Drullinger

Member, Technical Program Committee for CPEM 2000.

Leo Hollberg

Member, Program Committee, 17th Intl. Conf. on Coherent and Nonlinear Optics, ICONO-2001.

Member, BIPM Consultative Committee on Length (CCL).

Member, BIPM Working Group on the mis en pratique of the definition of the metre.

Co-Chair, Program Committee for Quantum Optics, International Quantum Electronics Conference.

Wayne Itano

Secretary-Treasurer of Topical Group on Precision Measurement and Fundamental Constants of the American Physical Society.

Member, Executive Committee of the Division of Laser Science of the American Physical Society.

Steve Jefferts

Member, Technical Program Committee, IEEE Frequency Control Symposium.

John Kitching

Member, Technical Program Committee for the Advanced Semiconductor Lasers and Applications Workshop.

Judah Levine

Chairman, BIPM Committee on GPS and GLONASS Time Standards.

Member, BIPM Working Group on TAI.

Chairman, JILA Committee on Computing and Electronics.

Michael Lombardi

Delegate Member, National Conference of Standards Laboratory.

Lisa M. Nelson

Co-Chair, Civilian GPS Service Interface Committee (CGSIC).

Thomas Parker

Member, Executive Committee for the Annual IEEE International Frequency Control Symposium.

Elected member, IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society Administrative Committee.

Member, Working Group on Two-Way Time Transfer of the CCTF.

Member, GPS Interagency Advisory Council (GIAC).

Heidi Quartemont

Administrative Officer Focus Group Committee

NIST Communications Committee

Donald B. Sullivan

Member, Executive Committee for the Conference on Precision Electromagnetic Measurements (CPEM).

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.

Marc Weiss

Member, Working Group on GPS Time Transfer Standards of the CCTF.

Member, Telecommunication Industry Subcommittee on Time and Synchronization.

Member, GPS Frequency Standards Working Group.

David J. Wineland

Member, National Academy of Sciences.

Member, DAMOP Nominating Committee

General Co-Chair, QELS 2002.

Member, Multidisciplinary University Research Initiative (MURI) Executive Advisory Board and Technical Advisory Committee "Information Physics" Non-classical Information Representation and Manipulation.

Member, AIP Visiting Scientist Program in Physics.

Member, Advisory Editorial Board, Optics Communication, 2000-2002.

QUANTUM PHYSICS DIVISION (848)

Steven Cundiff

Physics Panel Member, U.S. Civilial Research and Development Foundation (promotes collaborations with former Soviet Union).

James Faller

Member, Public Information Committee of the American Geophysical Union.

Chairman, University of Colorado Institute Directors Council.

Vice Chairman, APS Topical Group on Precision Measurement and Fundamental Constants.

Member, Directing Board, International Gravity Bureau.

Chair, Meeting at BIPM on New Techniques for Absolute Gravity.

Chair, Workshop at BIPM, Absolute Gravity Instrument Intercomparison (ICAG-2001).

Deborah S. Jin

Member, APS Division of Atomic, Molecular, and Optical Physics 2001 Thesis Prize Committee.

Stephen Leone

Chairman of subsection for NSF Committee of Visitors in Chemistry.

Chairman, DOE Panel on Novel Coherent Light Sources.

Chairman of APS Award Committee, Schawlow Prize Committee.

Member, NSF Selection Committee of APS Fellows for the Laser Science Division.

David Nesbitt

Vice Chair, Physical Chemistry Division, American Chemical Society.

Member, International Advisory Committee, Molecular Spectroscopy Symposium, Columbus, Ohio (1995-present).

Member, Advisory Committee, Optical Society of America/Interdisciplinary Laser Science.

Advisory Committee, International Conference on Near Field Optics. ❑

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

LABORATORY OFFICE

W.R. Ott is chairman and organizer of the biweekly "NIST Staff Colloquium Series." There were 12 colloquia in 2001.

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

C.W. Clark served as co-organizer of the Workshop on Computational Methods for Few-Body Dynamical Systems, held at NIST November 15-17, 2000. The workshop, co-sponsored by the American Physical Society, the National Science Foundation, and the University of Maryland, was attended by 70 researchers in atomic and molecular physics, chemistry, applied mathematics, and nuclear and particle physics.

ATOMIC PHYSICS DIVISION (842)

W.L. Wiese served on the organizing committee of 7^{th} International Colloquium on Atomic Spectra and Oscillator Strengths, at Belfast, Northern Ireland, August 2001 and is co-editing the proceedings. The colloquium had 90 participants from 17 different countries.

OPTICAL TECHNOLOGY DIVISION (844)

L.M. Hanssen organized and conducted the 2^{nd} Annual Workshop of the NIST-Industry Optical Properties of Materials Consortium, Gaithersburg, MD, December 2000.

T.A. Germer was session chair and program committee member for the "Surface Scattering and Diffraction for Advanced Metrology," Conference at the SPIE Annual Meeting, San Diego, California, August 2001.

B.C. Johnson planned and coordinated a "NIST Short Course on Temperature Measurement by Radiation Thermometry," at NIST, Gaithersburg, Maryland, with the support of Division 844, June 2001.

Y. Ohno and C.C. Miller organized and chaired the "NIST Short Course on Photometry," at NIST, Gaithersburg, Maryland, with the support of Division 844 and PTB in Germany, August 2001.

IONIZING RADIATION DIVISION (846)

J.M. Adams organized and chaired a special session entitled: Nuclear NIST, hosted at the 2000 American Nuclear Society/European Nuclear Society International Meeting, Washington, D.C., November 2000. (Trans. Am. Nucl. Soc. **83**, 2000).

J.M. Adams was a program committee member of a special session entitled Harnessing Light: Optical Science and Metrology at NIST, hosted at the SPIE International Symposium on Optical Science and Technology, San Diego, CA, July 29-August 3, 2001. (Proc. SPIE **4450**, 2001).

J.S. Nico chaired the session on Nuclear Astrophysics and Neutrinos at the American Physical Meeting in Washington, DC in April 2001.

K.G.W. Inn sponsored the Workshop on Estimating Uncertainties for Low-Level Radiochemical Analyses at NIST, November 12-17, 2000. Participants included representatives from reference laboratories, regulatory and monitoring agencies, commercial laboratories and armed forces and national laboratories conducting mass spectrometry, radiobioassay, environmental remediation, waste management, safeguards, commercial standards, intercomparison studies, and performance evaluation programs.

TIME & FREQUENCY DIVISION (847)

D. Howe led a tutorial program in May 2001 at the IEEE Frequency Control symposium to describe a set of new advanced statistical estimators and their application in time-prediction algorithms. The Allan variance has been an excellent basis for frequency stability measures since 1966 but has been problematic when used for tuning Kalman filters, which often play a main role in combining the best stability traits of individual clocks in an ensemble.

The lectures explained why and how to implement reliable statistical methods, particularly for managing ensembles. Over 50 participants made this tutorial one of the most lively and widely attended of the Symposium's 2001 programs.

D. Howe led the 26th Annual Time and Frequency Seminar held in Boulder, CO, May-June 2001. Among fundamental topics this year, the Seminar emphasized the present and future role and application of smaller, cheaper industrial atomic standards. New, more accurate measurement, characterization, and modeling techniques were introduced. While continuing to provide the best technical training for engineers, scientists, and technicians in the time and frequency field, the 2001 seminar also focused on calibration, traceability, and legal metrology issues for commercial and military standards laboratories. There were 20 participants.

J. Kitching organized a NIST-sponsored workshop on Chip-Scale Atomic Clocks. The workshop was arranged in response to a request from the Defense Advanced Research Projects Agency (DARPA) and held in Boulder on March 22, 2001. Attendance was by invitation only and included key representatives from industry, academia, and government laboratories. Talks presented during the workshop focused on recent advances in micro-resonator development and atomic-clock concepts that might be most amenable to miniaturization. The objective of the meeting was to assess the prospects for miniaturization to the chip level.

M. Lombardi and A. Novick conducted a two-day seminar called "Time and Frequency: Measurements and Applications" at the Measurement Science Conference in Anaheim, CA, January 2001. There were 12 attendees, most from calibration laboratories.

C. Nelson, D. Howe, and F. Walls led a 3-day workshop October 2000 on microwave-phase noise measurements that was sponsored by the Office of Naval Research and involved 31 participants from military and commercial organizations. The workshop focused on methodologies for precise measurement and reduction of phase noise of oscillator signal sources operating at frequencies up to 100 GHz.

M. Weiss served as chairman for the NIST Telecom Solutions "Workshop on Synchronization in Telecommunications Systems," held in Boulder, CO, April 2001. The workshop involved 100 participants and offered presentations on current requirements and methods of synchronization in telecommunications systems to beginners and advanced workers in the synchronization field.

QUANTUM PHYSICS DIVISION (848)

D.J. Nesbitt served on the advisory committee and organized, Optical Society of America/Interdisciplinary Laser Science, Fall Meeting, October 22-26, 2000. This conference serves as the annual meeting of Division of Laser Science of the American Physical Society and provides a forum for the latest work, both in laser source development and laser applications, to a broad range of important scientific problems in physics, chemistry and biology.

J. Ye and J. Hall served as conference chairs of a symposium, "Laser Frequency Stabilization, Standards, Measurement, and Applications" at the SPIE Conference in San Jose, CA, January 2001. ❑

JOURNAL EDITORSHIPS

LABORATORY OFFICE

Taylor, B.N., Chief Editor, *Journal of Research of the National Institute of Standards and Technology.*

Taylor, B.N., Member, Editorial Board, *Metrologia.*

ELECTRON & OPTICAL PHYSICS DIVISION (841)

Celotta, R.J., Co-editor, *Experimental Methods in the Physical Sciences,* Academic Press Series.

Clark, C.W., Member, Editorial Advisory Board, *Physics of Atoms and Molecules* (Kluwer Academic/ Plenum Publishers).

Clark, C.W., Member, Editorial Board, *Journal of Physics B: Atomic, Molecular, and Optical Physics.*

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.*

Tarrio, C.C., NIST Correspondent, *Synchrotron Radiation News.*

ATOMIC PHYSICS DIVISION (842)

Deslattes, R.D., Member, Editorial Board, *Physical Review A.*

Deslattes, R.D., Member, International Advisory Board, *Journal of Physics B.*

Deslattes, R.D., Member, Editorial Board, *Review of Scientific Instruments.*

Gillaspy, J.D., Editor, "Trapping Highly Charged Ions: Fundamentals and Applications," *NOVA Science Publishers.*

Reader, J., Editor, "Line Spectra of the Elements," *Handbook of Chemistry and Physics*, CRC Press.

Wiese, W., Associate Editor, *Journal of Quantitative Spectroscopy and Radiative Transfer.*

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.

Williams, C., Associate Editor, *Quantum Information & computation,* Rinton Press.

OPTICAL TECHNOLOGY DIVISION (844)

Hougen, J.T., Member, Editorial Advisory Board, *Journal of Molecular Spectroscopy.*

Johnson, B.C., Guest Editor for Tempmeko 2001, 8^{th} International Symposium (Berlin, Germany).

IONIZING RADIATION DIVISION (846)

Bergstrom, P.M., Editor, *Bulletin of the International Radiation Physics Society.*

Collé, R., Member, Editorial Board, *Journal of Research National Institute of Standards and Technology.*

Coursey, B.M., Editor-in-Chief, Editorial Board, *Applied Radiation and Isotopes.*

Coursey, B.M., Member, Editorial Board, *Nuclear Medicine and Biology.*

Coursey, B.M., Member, Editorial Board, *Cardiovascular Radiation Medicine.*

Inn, K.G.W., Member, Editorial Review Board, *Radioactivity and Radiochemistry.*

Soares, C.G., Member, Editorial Advisory Board, *Vascular Radiotherapy.*

Soares, C.G., Editor, *Cardiovascular Radiation Medicine.*

Soares, C.G., Guest Associate Editor, *Medical Physics.*

TIME AND 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, Advisory Editorial Board, *Optics Communication.*

Wineland, D.J., Managing Co-Editor, *Quantum Information and Computation.*

QUANTUM PHYSICS DIVISION (848)

Cornell, E.A., Member, *Physical Review Letters* Review Committee.

Leone, S.R., Member, Advisory Editorial Board, *Chemical Physics Letters.*

Leone, S.R., Editor, *Annual Reviews of Physical Chemistry.*

Nesbitt, D.J., Member, Editorial Board, *Journal of Chemical Physics.* ❑

INDUSTRIAL INTERACTIONS

COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENTS - CRADAs

ATOMIC PHYSICS DIVISION (842)

■ **Atomic Data for Lighting Research.** The Atomic Spectroscopy Group has a CRADA with the Electric Power Research Institute (EPRI) to produce basic atomic data for lighting research. This is part of a joint EPRI-lead effort with Los Alamos National Laboratory, the University of Wisconsin, the University of Illinois, General Electric, Philips Lighting, and Osram/Sylvania to find new approaches to the design of high-efficiency lighting. The NIST group is measuring wavelengths and transition probabilities for complex atomic spectra using high-resolution Fourier transform spectrometry, making radiometric measurements of mercury discharges, and using x-ray sources to map spatial distributions of emitters in high intensity discharge lamps.

OPTICAL TECHNOLOGY DIVISION (844)

■ **Radiation Thermometry for RTP.** NIST entered into a CRADA agreement with Applied Materials (CRADA CN-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." The NIST Principal Investigators for both CRADA agreements were R.D. Saunders, B.K. Tsai, F.J. Lovas, and D.P. DeWitt.

■ **NIST/Industry Consortium on Optical Properties of Materials (OPMC).** The OPMC has been established to provide NIST with direct input from industry concerning industry's needs for optical properties of materials data, standards, calibration services, materials research, measurement methodologies, etc. Currently six industrial and two academic members representing a variety of fields are working with NIST personnel from several divisions under the Consortium CRADA agreements. The Optical Technology Division is currently working with OPMC members Raytheon, Surface Optics Corporation, John Hopkins University-Applied Physics Laboratory, Labsphere Inc., Kodak, Hoffman-LaRoche and Zeiss. The second annual workshop was held at NIST in Gaithersburg, MD with presentations by both NIST and industrial participants on current activities related to optical properties.

IONIZING RADIATION DIVISION (846)

■ **Remote Control of Alanine Dosimeter Measurements.** The Radiation Interactions and Dosimetry Group under a CRADA is working with Bruker Instruments, Inc., Billerica, MA, to facilitate software development to control alanine dosimeter measurements remotely for internet-based radiation calibration services.

■ **Calibration Services for Low-Energy Electron Beams.** The Radiation Interactions and Dosimetry Group is working with GEX Corporation under a CRADA to jointly develop and field test a transfer calibration service for industrial users of electron beams with energies less than 500 kV.

■ **Measurement of Radiation Dose and Dose Distributions in Three Dimensions Using an Automated Water Phantom.** The Radiation Interactions and Dosimetry Group has set up a CRADA with the Photoelectron Corporation, MA, to explore the use of an automated water phantom and small volume ionization chamber combination for the dosimetry of low-energy photon sources to work towards the goal of developing an absorbed-dose standard for photon brachytherapy sources. Essential to such standards is the measurement of absorbed dose rate in water or water-equivalent media. Traditional automated water phantoms move detectors in a Cartesian coordinate system. While this system is convenient for beam dosimetry, it poses problems for the dosimetry of brachytherapy sources. Since the radiation fields produced by these sources are inherently cylindrical in nature, detectors that have angular dependent responses will perform poorly when scanned in a field produced by a brachytherapy source. Scanning the detector in cylindrical coordinates, however, will keep the detector surface parallel to the brachytherapy source axis and hence avoid angular dependence problems. This enhancement in automated water phantom design will be particularly crucial in intravascular brachytherapy applications where source to detector distances are very small and angular and radial distance accuracy is extremely important. Various source and detector combinations will be used in the water phantom to measure three-dimensional dose distributions in water for comparison with the results of other determinations, such as with radiochromic film. Software will be developed to control the water phantom for these measurements, as well as to acquire and condition the data obtained. Mounting systems for the sources and detectors will be designed and built. Sources to be used will include but not be limited to portable low-energy x-ray probe sources, ^{90}Sr/Y seeds and plaque sources, ^{32}P wires and balloons, ^{192}Ir seed ribbons, ^{125}I seeds and ^{103}Pd seeds. Detectors employed will include but not be limited to small volume ionization chambers, scintillators, and diodes. Accuracy and reproducibility of the detector positioning will be examined and quantified.

■ **X-Ray Imaging System.** Industrial Quality, Inc. of Gaithersburg, MD, in a CRADA with the Radiation Interactions and Dosimetry Group, is developing and testing an x-ray imaging system (variable-depth x-ray laminography) for manufacturing inspection and quality control of critical laminated structures, such as printed-circuit boards.

■ **Pressure Vessel Dosimetry.** J.M. Adams and A.D. Carlson, via a CRADA with Ohio University, are involved in research for the DOE Nuclear Energy Research Initiative (NERI) on measurement of neutron inelastic scattering cross sections in iron. These standard methods and reference data are critical for the design of nuclear-reactor pressure vessels that are subjected to neutron-embrittlement of the steel structures.

■ **Standards and Traceability of the Radiopharmaceutical Industry.** The Radioactivity Group and the Nuclear Energy Institute, under the auspices of a CRADA, work with the radiopharmaceutical industry to develop and provide necessary standards and calibration services to ensure measurement quality in drug manufacturing and use. The traceability program operates by distributing calibrated standards on a regular basis to participants as blind samples, and as standard reference materials to the public.

■ **Standards and Traceability of the Nuclear Power and Standards Suppliers.** The Radioactivity Group works under a CRADA with a group combining the nuclear power industry and standards production laboratories to provide standards and traceability services. These sources are used in power plant monitoring of the waste, normal operations, environmental monitoring, etc.

TIME AND FREQUENCY DIVISION (847)

■ **Development of an Optical Frequency Standard.** J. Bergquist, the Ion Storage Group, and L. Hollberg are collaborating under the terms of a CRADA with Timing Solutions Corporation to develop an optical frequency standard with an uncertainty and fractional instability that are lower than 1×10^{-17} by spectrally narrowing a laser through its short-term lock to a high-finesse optical cavity and its long-term lock to a narrow transition in a single laser-cooled mercury ion or a crystallized ensemble of laser-cooled ions.

■ **Two Way Satellite Time Transfer.** D. Howe is collaborating under the terms of a CRADA with Timing Solutions Corporation to set up and implement two-way satellite time transfer to support and/or evaluate other existing or proposed time-transfer technologies.

■ **Secure Time Distribution.** J. Levine is collaborating under the terms of a CRADA with Certified Time, Inc., for the purpose of studying secure methods of time-data distribution offering the greatest precision across open networks such as the Internet and across closed networks adjoining the Internet such as are common in the commercial sector.

QUANTUM PHYSICS DIVISION (848)

■ **Development of Instrumentation for Ultrafast Optics.** S.T. Cundiff has a CRADA with ThorLabs, Inc. (Newton, NJ), to develop instrumentation for ultrafast optics. Currently the project is focusing on developing compact and inexpensive designs for autocorrelators, which are 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 Hewlitt Packard on the development of 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.

■ **Development of Diode-Pumped Solid State Lasers for LIDAR Application.** J. Ye has established a CRADA with Coherent Technology Inc. based in Colorado.

■ **Active Stabilization and Synchronization of Femtosecond Lasers.** J. Ye has established a CRADA with the Kapteyn-Murnane Laboratories LLC based in Boulder, Colorado.

INDUSTRIAL INTERACTIONS

INFORMAL COLLABORATIONS

ELECTRON & OPTICAL PHYSICS DIVISION (841)

■ **Measurement of the Intrinsic Birefringence of Calcium Fluoride.** SEMATECH, in support of the semiconductor industry's effort to develop DUV microlithography using 157 nm light, has requested NIST help in fully characterizing refractive lens materials that have high transmission at 157 nm. Thus far the prime candidate material for stepper lenses is calcium fluoride (CaF_2), one of the few materials that is highly transparent at 157 nm. Experimental work in the Atomic Physics Division (842) revealed that CaF_2 has a significant amount of intrinsic birefringence at 157 nm, a fact that was totally unexpected and that will force the developers of 157 nm microlithography to make major adjustments to their designs. Theoretical work in the Photon Physics Group collaboratively performed with the Optical Technology Division (844) corroborated the experimental results and described the symmetry properties of the birefringence which will allow some cancellation of its effects by the proper orientation of different lenses of the stepper.

■ **Improved Accuracy for the NIST/DARPA Reflectivity Facility.** The EUV-LLC, a consortium of Intel, Motorola, AMD, Micron Technology, Infineon Technologies, and IBM, has embarked on a program to demonstrate the feasibility of EUV lithography for the next generation of microcircuit fabrication. Proper operation of the EUV stepper requires that its EUV mirrors be measured to unprecedented accuracy: i.e., 0.1% in reflectivity and 0.01% in peak wavelength. The Photon Physics Group is in the process of upgrading the NIST/DARPA Reflectometry Facility on SURF III to attain this level of accuracy. Presently the NIST/DARPA instrument is the only one in the world large enough to measure the large mirrors in an EUV stepper. This year we have measured the largest mirror of a prototype stepper recently commissioned by the EUC-LLC. We expect to play an increasing role in their effort, starting with our participation in an ongoing international intercomparision of reflectivity measurements to establish a more accurate scale for reflectivity.

■ **Development of EUV Pulsed Radiometry.** The Photon Physics Group is working closely with the EUV-LLC to develop a calibration method to accurately characterize the EUV wafer-plane dosimeters they will use in their EUV steppers.

■ **Development of EUV Filter-Detector Packages.** The Photon Physics Group has continued its long-standing collaboration with International Radiation Detectors, Inc. of Torrance, CA. The Group has made several measurements in support of IRD's effort to develop photodiodes with an Sn or In film deposited directly onto the active area. Such a film would render the device insensitive to radiation outside a band in the far ultraviolet, enabling the direct observation of important solar emission lines while minimizing the effects of other far ultraviolet emissions outside the wavelength range of interest.

■ **Development of Solar Blind Photodiodes.** The Photon Physics Group has worked with SVT Associates of Eden Prairie, MN to characterize GaN and AlGaN photodiodes. These devices are inherently solar blind, *i.e.*, they do not respond appreciably to visible or infrared radiation. In some applications, the utility of current Si photodiodes is limited by the presence of a visible and infrared radiation background that is not of interest to the experimenter. We have made the first experimental measurements of detector quantum efficiency in the far ultraviolet, and have evaluated different device architectures. At wavelengths less than 200 nm, Schottky devices exhibit a higher quantum efficiency than p-i-n devices. SVT Associates is currently fabricating large area devices; the largest active area achieved to date is 5 mm^2.

ATOMIC PHYSICS DIVISION (842)

■ **Wavelengths of VUV Lasers for Lithography.** For deep UV photolithography with excimer-lasers, precise wavelength specification and control is a critical requirement, because chromatic effects in the projection optics is a limiting factor in reducing the size of circuit elements on new generations of integrated circuits. As a result of contacts with laser manufacturers, the Atomic Spectroscopy Group performed a collaborative experiment with the Lambda Physik Corporation, a subsidiary of Coherent, Inc., to measure accurate wavelengths for lasing lines at 157 nm emitted by a molecular fluorine laser. A Lambda Physik fluorine laser, sent from Germany especially for this experiment, was mated to the NIST 10 m normal-incidence vacuum spectrograph with a novel beam line designed to eliminate shifts in wavelength that might be caused by slightly different illumination of the optics by the laser and the Pt/Ne hollow cathode calibration lamp. Wavelengths for six lasing lines were measured to an accuracy of 0.00010 nm. Three of the six were lasing lines that had not been observed previously. Further work is continuing with the Lambda Physik Co. to address wavelength calibration problems for ArF lasers operating at 193 nm.

■ **Thin Film and Multilayer Metrology.** Our work on x-ray analysis of thin film and multilayer structures is motivated by applications in the area of semiconductor materials deposition and processing. More specifically, we have maintained a long-standing relationship with SEMATECH and its member companies in the application of high-resolution x-ray tools to the solution of specific manufacturing problems. Based on this industrial connection, we have initiated the formation of the Consortium for High-resolution X-ray Calibration Strategies. The overall goal of this Consortium will be to support the use and interpretation of high-resolution x-ray analytical techniques by U.S. semiconductor materials and tool suppliers. The final technical program for the critical tasks of the Consortium has been established, and a Cooperative Research and Development Agreement has been drafted and approved by NIST. We are currently engaged in technical and management discussions with high resolution x-ray equipment vendors (Bede Scientific, Bruker AXS, Philips Analytical), semiconductor materials processing companies (Intel, AMD, IBM, IQE, TriQuint), and production tool suppliers (ThermaWave, EMCORE) to formally initiate the work of the Consortium. Exploratory contacts with other potential industrial members are currently being made.

■ **X-ray Source Characterization with Crystal-Diffraction Spectrometry.** The Quantum Metrology Group is consulting with the Pulse Sciences Division of Titan Systems Corporation on the x-ray spectral characterization of high-power sources used to test satellite components. Titan Systems Corporation is performing these tests for the Defense Threat Reduction Agency. The group has provided assistance in the areas of spectrometer design and ray-tracing software, reflectivity and absorption data, and relevant publications and reports.

■ **Optical Computer Aided Tomography for Plasma Uniformity Control.** The plasma radiation group has an ongoing effort with ATP Intramural funding to develop a plasma uniformity process control sensor based on optical computer aided tomography. Real or in-time measurements of plasma uniformity is of interest to the semiconductor industry and plasma etching tool manufacturers such as LAM Research.

■ **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 simulation software for near-field scanning optical microscopy.

■ **Stress Induced and Intrinsic Birefringence in UV Materials.** We have been pursuing a SEMATECH sponsored project to determine the stress-induced birefringence properties of all the materials potentially of use for deep UV precision optics, including CaF_2, BaF_2, SrF_2, LiF, and fused silica. These parameters are needed for the design of the optics of 157 nm lithography systems. In a separate investigation we uncovered a different birefringence phenomena that is *intrinsic* to these materials, which is at least as important as the stress-induced effect. Using unique UV polarimetry and interferometric apparatuses we built, we have been measuring these parameters on materials from all the leading UV materials suppliers in the U.S. and the world. [ACT Optics (Cleveland, OH), Corning/Optovac (Brookfield, MA), Corning (Corning, NY), Korth (Germany), Saint-Gobain/Bicron (Solon, OH), Schott Glas (Germany, U.S. subsidiary: Duryea, PA)] We deliver these results directly to all the 157 nm lithography system designers, including ASML (Netherlands, U.S. subsidiary: SVGL, Wilton, MA), Canon (Japan), Corning/Tropel (Fairport, NY), Nikon (Japan), Optical Research Associates (Pasadena, CA), Ultratech Stepper (Wilmington, MA), and to the key system component manufacturers, including Cymer (San Diego, CA), Hinds Instruments (Hillsboro, OR), and Lambda Physik U.S.A. (Ft. Lauderdale, FL).

OPTICAL TECHNOLOGY DIVISION (844)

■ **Infrared Optical Properties of Materials Characterization.** L.M. Hanssen worked with ITT industries Aerospace Division of Fort Wayne, IN to evaluate and develop high emittance coatings for blackbody sources for infrared applications. Measurements of directional-hemispherical reflectance and bi-directional reflectance distribution function were performed at NIST to support this effort.

L.M. Hanssen worked with the Tactical Defense Systems group at MIT Lincoln Laboratory, to analyze the infrared emittance properties of coatings used for the Airborne Laser Project.

S. G. Kaplan and L. M. Hanssen worked with Surface Optics Corporation to establish higher accuracy reflectance scales for their commercial instrumentation that are used by a number of U.S. and U.K. aerospace companies. Transfer standard reflectance samples (high reflectance infrared mirrors and infrared diffusers) are being spectrally characterized for this purpose.

IONIZING RADIATION DIVISION (846)

■ **Methods to Calibrate and Characterize Beta-Particle Brachytherapy Sources.** C.G. Soares is working with Novoste Corp. of Atlanta, GA; Guidant VI Corp. of Houston, TX; Radiance Medical Systems of Irvine, CA; Radiovascular of Washington, DC; Best Industries of Springfield, VA; Cordis Corp. of Warren, NJ; Medtronic AVE of Santa Rosa, CA; Xoft Microtube of Fremont, CA; AEA Technologies of Braunschweig, Germany; and BEBIG of Berlin, Germany to develop methods to calibrate and characterize intravascular brachytherapy sources for use in preventing restenosis after angioplasty therapy. The procedure of angioplasty is performed over 500,000 times in the U.S. each year, and in about 40 % of the cases, restenosis occurs, requiring another treatment. Research has shown that a dose of about 20 Gy, delivered to the wall of the blood vessel after the angioplasty has been performed, is effective in inhibiting restenosis. NIST has taken an early and leading role in developing methods for the calibration of the sources used for this therapy, employing the NIST extrapolation chamber and radiochromic dye film. New measurement methods are under active research.

■ **Intravascular Brachytherapy.** Members of the Radiation Interactions and Dosimetry Group are working with Guidant, Inc. in (a) performing electron-photon transport Monte Carlo simulations to calculate the spatial distribution of absorbed dose in water around proposed ^{32}P sources, and (b) calibrating well-ionization chambers in terms of reference absorbed dose and activity for existing ^{32}P sources.

■ **Interferometry and Tomography Imaging.** M. Arif and D.L. Jacobson in the Neutron Interactions and Dosimetry Group are working with Dr. Gregg Downing, with Nova Scientific, to develop a new, high resolution, neutron detector screen for neutron imaging. The performance of the new screen will be demonstrated using the neutron interferometry and tomography imaging facilities.

■ **Standards and Traceability for the Army.** M. Unterweger and P. Hodge are coordinating the traceability program for the U.S. Army, which involves the calibration and measurement of swipe samples of various radionuclides to assess the performance of U.S. Army measurement laboratories (in addition to military ones listed last year), has been in progress. The results of the first ^{63}Ni samples have been reported to the participating laboratories. Samples of ^{241}Am, ^{60}Co, and ^{137}Cs were sent to the participating laboratories and the results compiled and reported to them. Samples of ^{63}Ni and ^{90}Sr were distributed and are being measured by the participating laboratories.

■ **Glow Discharge Resonance Ionization Spectroscopy Investigations.** L. Pibida and R. Hutchinson, in collaboration with Pacific Northwest National Laboratory (PNNL) and the University of Mainz, Germany, have extended our RIMS system. Measurements of ^{135}Cs/^{137}Cs isotopic ratio in burn up samples were performed as well as investigations in extending the NIST system to study difference radioisotopes in environmental samples. The ultimate purpose is to assay environmental radioactivity either in the original matrix or with minimal chemical steps performed before measurement with the highest efficiency and selectivity achievable.

■ **Cryogenic Calorimetry**. R. Collë and B. Zimmerman have been working with SRL, Inc., of Boston, MA, which received SBIR phase II funding for the development and production of 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, beta and some isomeric (less than 50 keV) gamma-ray emission radioactivities.

■ **Storage Photostimulable Phosphor Imaging.** Radioactive contamination poses a special challenge to environmental clean-up efforts, and site characterization and post-remediation verification require innovative measurement techniques and strict quality control. An important part of this effort involves the production and maintenance of large area sources for calibration of instruments used in military, medical and environmental applications. The uniformity and accurate measurement of these sources impact directly on the delivery of quality services in these applications. Along with NeuTek, M. Unterweger, L. Karam, and P. Hodge have been exploring the potential of applying a new radiation imaging concept based on the storage photostimulable phosphor (SPP) technique for radioactivity measurement of large area sources. The combination of high resolution, high sensitivity with a linear response of over 10^5 dynamic ranges makes the SPP imaging detector especially suited for this task. The SPP measurement process is non-destructive and quick, and is capable of providing a detailed radioactivity distribution map of a test source, a capability very much needed in source characterization.

■ **Characterization of the Fuji Imaging System for Large-Area Alpha Sources.** A contract with Nucor Corporation for the characterization of the Fuji imaging system for use as a calibration tool for large-area alpha sources has been completed. Experimental verification of the linearity corrections is being undertaken by M. Unterweger, P. Hodge, and L. Karam. If successful, it will enable the system to be used for the calibration of low-level alpha-emitting sources.

■ **Radionuclide Speciation in Soils and Sediments.** This project, led by K. Inn and C. McMahon, addresses the identification of radionuclide partitioning in soils and sediments. The approach involves the development of the NIST Standard Extraction Protocol for identifying the distribution of radioactive elements in soils and sediments. The procedure is designed to partition a soil or sediment sample into six operationally defined fractions (HNO_3, HF, MgCl, HOAC, H_2O_2, $NH_2OH{\cdot}HCl$). A full-factorial experimental design/data analysis methodology was used to establish the optimum conditions for these six extractions. Reaction time, reagent concentration, and reaction temperature 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 optimized method developed thus far.

■ **Development of Standards for Radioimmunotherapy.** The radionuclide ^{166}Ho is has been investigated for a wide variety of therapeutic applications in nuclear medicine. NeoRx, Inc. and partners are currently investigating ^{166}Ho for use in radioimmunotherapy of small cell cancers. As part of any application to the Food and Drug Administration for approval of radiopharmaceuticals for use in humans, NeoRx must demonstrate that they can accurately measure the amount of radioactive ^{166}Ho present in the drug. The Radioactivity Group has worked with NeoRx, Inc.; Missouri University Research Reactor; International Isotopes, Inc.; and ABC Laboratories to develop a national standard for this radionuclide, verifying preliminary work previously performed at NIST. Work was also performed to transfer this primary standard to the NIST ionization chamber, to facilitate the dissemination of the national standard. Previous work was done using a solution of holmium in the form of a chloride. Work this year extended the primary measurement to solutions of the drug formulation, ^{166}Ho-DOTMP, and developed "transfer standards;" i.e., calibration factors for commercially available re-entrant ionization chambers for specific geometries and solutions.

QUANTUM PHYSICS DIVISION (848)

■ **Collaboration with IBM.** Development of novel measurement tools for latent images in photolithographic films using infrared near field optical microscopy. IBM provides samples of chemically amplified polymer photoresists and infrared near field optical microscopy techniques are developed in the laboratories of S.R. Leone to measure the line dimensions and photoacid diffusion under different conditions of bake and irradiation. The results are important to characterize polymer photoresists for state-of-the-art line dimensions.

■ **Spectral Broadening in Microstructured Optical Fiber**. S.T. Cundiff, J.L. Hall, and J. Ye are studying the spectrally broadened frequency comb produced when an ultrashort pulses propagates through microstructured optical fiber. The microstructured optical fiber is being provided by Lucent Technologies (Murray Hill, NJ). The spectrally broadened frequency comb is being used for optical frequency measurement and synthesis.

■ **Optical Science and Engineering Program**. OSEP is a multi-department, interdisciplinary collaboration among JILA, NIST, and the University of Colorado's departments of Physics, Electrical Engineering and Computer Science, and Chemistry and Biochemistry. The OSEP is an innovative graduate training program designed to meet the growing demand for individuals who have 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, an ability to work in teams, and clarity in oral and written communication. By expanding its connections to include the department of Electrical and Computer Engineering, and 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. ❑

OTHER AGENCY RESEARCH AND CONSULTING

LABORATORY OFFICE (840)

W.R. Ott is the NIST liaison for NIST's Ballistic Missile Defense Organization (BMDO) metrology projects (about $1 M program in the Physics Laboratory).

W.R. Ott gave a presentation on directions of research in the Physics Laboratory and participated in discussions on the future of Atomic, Molecular, and Optical Physics research at a meeting of the NRC Committee on Atomic, Molecular, and Optical Physics.

ELECTRON & 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.

C.W. Clark worked on physical science applications of the NIST Digital Library of Mathematical Functions, for the National Science Foundation.

C.W. Clark worked on quantum communication for the Defense Advanced Research Projects agency.

M. Furst performed absolute EUV radiometry for NASA to improve the reliability and accuracy of space-borne spectrometers.

A.H. Band (with G.A. Klouda, Div. 837), United States Air Force: Upgrade of NIST Low Level Counting System.

T.B. Lucatorto served on a review panel for the New York Scientific, Technical and Academic Research Program.

J.A. Stroscio, R.J. Celotta, and D.T. Pierce performed research for the Office of Naval Research: Electronics and Magnetism at the Nanometer Scale.

J. Unguris, D.T. Pierce and R.J. Celotta performed 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.

ATOMIC PHYSICS DIVISION (842)

J.D. Gillaspy, research for NASA in collaboration with the Harvard-Smithsonian Center for Astrophysics: x-ray data from highly charged ions, in support of Chandra. Testing of microcalorimeter, in support of the development of detectors for future satellite observatories.

L.T. Hudson, research for the Naval Research Laboratory designing, fabricating, and calibrating a cluster of diagnostic x-ray crystal spectrometers for the diagnosis of plasmas at the National Ignition Facility of Lawrence Livermore National Laboratory.

P. Julienne and W. Phillips (with C.W. Clark, Div. 841), worked on atom-laser design for the Office of Naval Research.

Y.K. Kim, research for DOE: Theory of electron-impact ionization for application to magnetic fusion.

W. Phillips and others, research for ONR on laser cooling and trapping and cold collisions.

W. Phillips and S. Rolston, research for NASA on a Primary Atomic Reference Clock in space (Time and Frequency Division is also involved).

W. Phillips, C. Williams, and others, research for DARPA on the use of neutral atoms for quantum information processing (with Div. 841).

L. Podobedova and A. Robey, research for NASA: Compilation of data to support the Chandra X-ray Observatory Emission Lines Project

J. Reader, C. Sansonetti, and E. Saloman, research for DOE: Critical compilations of atomic spectroscopic data of magnetic-fusion interest.

J. Reader, research for DOE: Spectroscopy of highly ionized atoms to obtain data needed for diagnostics of magnetic-fusion plasmas.

J. Reader, research for NASA: compilation and dissemination of spectral data for light elements in collaboration with Institute for Spectroscopy, Moscow.

C. Sansonetti and J. Reader, research for NASA: Wavelengths and isotope shifts for heavy elements needed for interpretation of spectra of chemically peculiar stars.

W. Wiese principal investigator (PI), research for the Office of Fusion Energy Science, 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, C. Sansonetti, E. Saloman, 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.

C. Williams, Advance Research and Development Activity (ARDA) National Security Agency (NSA) for Neutral Atom Quantum Computing with Optical Lattices (PI).

C. Williams, Defense Advanced Research and Development Activity (DARPA) for a Scalable Quantum Information Network (PI).

OPTICAL TECHNOLOGY DIVISION (844)

T. Early, funded by the Environmental Protection Agency: Maintain a monitoring site for the National UV Monitoring Center.

T. Early, S. Brown, D. Allen, and C. Johnson, in collaboration with Lockeed Martin, Scripps Institute of Oceanography and Goddard Space Flight Center: Perform radiometric calibration of the Earth Polychromatic Imaging Camera (EPIC).

T. Early and D. Allen, research for the DOE to look at fluorescent standards.

G. Eppeldauer, research for the USAF: Develop spatially uniform infrared working standard radiometers for the 5 µm to 20 µm wavelength range.

G. Eppeldauer, S. Brown, and K. Lykke, research for the USAF: Develop a Spectral Irradiance and Radiance Response Calibration with Uniform Sources (SIRCUS) reference facility to increase accuracy of detector based radiometric, photometric, color, and temperature measurements.

G. Eppeldauer and H. Yoon, research for the U.S. Air Force (USAF): Develop high sensitivity InSb radiometer standards and a detector-based calibration method and procedure to measure infrared irradiance of target simulators.

G. Eppeldauer and J. Lehman (NIST Boulder), research for the USAF: Develop standards quality pyroelectric detectors and radiometers to extend the high accuracy spectral power responsivity measurements from the visible wavelength range to the ultraviolet and infrared.

G.T. Fraser and D.F. Plusquellic, research for the Upper Atmosphere Research Program of NASA for Infrared Spectroscopy Studies on Atmosphere Molecules.

G.T. Fraser, D.F. Plusquellic, and W.J. Lafferty, research for the NASA AQUA program to provide spectroscopic measurements of the water-vapor continuum absorption.

G.T. Fraser, research for the Army on the validation of FTMW for quantitative analysis.

R. Gupta, measurements on UV degradation of photodiodes and optical constants of calcium fluoride for MIT Lincoln Labs and Optical Stepper Manufacturer.

L.M. Hanssen and S. Kaplan, performed research for the U.S. Navy: Support for the Navy Primary Standards Laboratory Fourier Transform based Blackbody calibration facility.

L.M. Hanssen and G. Eppeldauer, performed research for the Ballistic Missile Defense Organization: Pyroelectric detector calibration project.

L. Hanssen and S. Kaplan, research for the USAF: Variable angle and temperature emittance for target discrimination.

E. Heilweil, consulting with Drs. P. Manos and M. Meadows, The Gillette Company, Gaithersburg, MD and Boston, MA: Use infrared imaging cameras to measure temperature increase and heat flow in laser stimulated hair and hair follicle samples.

E. Heilweil, collaborating with Drs. D. Guyeski and J. Pelegrino (NIST, EEEL): Use femtosecond pump-probe methods to directly measure carrier relaxation times of low-temperature grown GaAs films used for THz generators and detectors.

E. Heilweil, in collaboration with Drs. O. Zohar and D. Alkon, National Institute of Neuronal Disorders and Stroke, NIH: NIST's mid-infrared camera systems are being used to image heat release from electrically stimulated neutrons in live rat brain sections. We also measure temperature-sensitive phosphorescence lifetimes of a europium chelate in solution and model cell membranes.

J. Houston and J. Rice, research for the U.S. Navy and USAF CCG: Develop HACR2, a new primary radiometric standard.

C. Johnson, D. Allen, S. Brown, T. Early, J. Fowler, C. Gibson, J. Rice, and H. Yoon, research for NASA: EOS calibration and validation program.

C. Johnson and H. Yoon, research for the USAF on the development of 2.25 im radiation thermometer.

C. Johnson, S. Brown, and H. Yoon, research for NOAA: Marine optical buoy ocean color program.

C. Johnson, S. Brown, and H. Yoon, research for NASA: SeaWiFS calibration and validation program.

S. Kaplan, research for the Johns Hopkins University (JHU) Applied Physics Laboratory on the index of refraction for Sapphire, collaboration with M.E. Thomas of JHU.

S. Kaplan, research for NOAA: measure the infrared transmittance of filters for the Geostationary Operational Environmental Satellite (GOES) Sounder and Imager instruments.

S.R. Lorentz and R.U. Datla, research for Ballistic Missile Defense Organization: Low Background IR (LBIR) calibrations.

S.R. Lorentz, J.P. Rice, and K. Lykke, research for NASA: calibrated a space-flight radiometer, NISTAR, for the NASA Triana mission.

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.

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, S.G. Kaplan, L.M. Hanssen, and R.U. Datla, research for the BMDO (USAF): Development of measurement methodologies, calibration services and standards for infrared detectors, blackbodies, and spectral emittance, reflectance and transmittance of materials.

A. Migdall, research for DARPA on a scalable quantum information network.

C.C. Miller and T. Early, research for providing calibration services for retroreflectance for the National Cooperative Highway Research Program.

Y. Ohno and R. Saunders research for U.S. Navy: Wire Contrast Measurement Standards (CCG 00-462).

J.P. Rice, research for Los Alamos National Laboratory (LANL): *In-situ* verification of the infrared radiometric scale used at the LANL space-simulating calibration chamber by development of the NIST Thermal-infrared Transfer Radiometer.

J.P. Rice, consulting for NOAA, USAF and NASA: wrote the NIST section of the NPOESS Preparatory Project [NPP] Calibration and Product Validation Plan for the National Polar-Orbiting Operational Environmental Satellite System (NPOESS).

J.P. Rice and C. Johnson, research for NASA: participated in the 2001 IR Intercomparison Workshop at the University of Miami, Rosential School of Marine and Atmospheric Sciences, Miami, FL.

J.P. Rice, J.J. O'Connell, and D. Allen, research for NOAA: measured GOES calibration chamber sources in Ft. Wayne, IN.

J.P. Rice, research for DOE: measured LANL calibration chamber sources in Los Alamos, NM.

E.L. Shirley and R.U. Datla, Infrared Test Chamber Analysis and Optical Modeling for the Ballistic Missile Defense Organization.

H. Yoon, D. Allen and C. Johnson, research on the development of a 0.65 μm radiation thermometer.

IONIZING RADIATION DIVISION (846)

J.M. Adams and A.D. Carlson, funded via CRADA with Ohio University: research for the DOE Nuclear Energy Research Initiative (NERI) grant on measurement of neutron inelastic scattering cross sections in iron.

M. Arif and D.L. Jacobson, with support from the DOE: Research on neutron imaging of hydrogen fuel cells.

A.D. Carlson, with support from the DOE: Research on neutron cross section standards, both measurements and evaluations.

J.T. Cessna with support from Environmental Protection Agency (EPA): Perform traceability testing and ongoing review of appropriateness of tests for EPA's primary radon laboratory.

R. Collé, through an interagency agreement between the NIST Radioactivity Group and the U.S. EPA: Provide technical assistance to EPA in designing and constructing a pulse-ionization-chamber-based, primary radon-222 calibration system at its Las Vegas Laboratory. This work includes development of various testing, operating, and quality assurance protocols for the new system.

T.R. Gentile and A.K. Thompson, through an interagency Agreement with the DOE: Research on polarized ^{3}He in neutron scattering.

K.G.W. Inn and Z.C. Lin with support from University of Utah (UOU), LANL, LLNL, and Duke Engineering & Services: Evaluate the most promising atom-counting techniques of quantifying μBq level of ^{239}Pu and ^{240}Pu in urine for DOE's Marshall Island Resettling Program.

K.G.W. Inn with support from the 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, with support from the DOE Radiological and Environmental Sciences Laboratory, Idaho Falls: Radiochemistry quality assurance to improve the traceability and strengthen the credibility of their Radiobioassay Laboratory Accreditation Program.

K.G.W. Inn, Z. Lin, Z.Y. Wu and C. McMahon, through an interagency agreement between NIST and the U.S. Environmental Protection Agency: Continue to develop metrology and verification techniques for radionuclide traceability evaluation in support of the National Voluntary Laboratory Accreditation Program's Proficiency Testing Supplier's program. The Ionizing Radiation Division is also providing technical support to NVLAP for the accreditation of Proficiency Testing Providers.

K.G.W. Inn, Z. Lin, C. McMahon, and Z. Wu, through an interagency agreement with the DOE/EM National Analytical Management Program: Conduct traceability evaluations of their Reference Laboratories -- the Environmental Measurements Laboratory (NY) and the Radiological and Environmental Sciences Laboratory (ID).

L.R. Karam et al., with support from the NEI and the Food and Drug Administration (FDA): Provide standards and calibrations for the primary standards laboratory of the FDA.

L.R. Karam and M.P. Unterweger, with support from the U.S. Army: Perform traceability testing of U.S. Army primary standards laboratory.

L.R. Karam and M.P. Unterweger, with support from the 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. ^{63}Ni samples have been distributed to the participating laboratories.

L.R. Karam and M.P. Unterweger, with support from the U.S. Air Force: Provide traceability measurements and techniques assessments for the U.S. Air Force primary laboratory.

Z.C. Lin and K.G.W. Inn, with support from the Armed Forces Radiobiology Research Institute (AFRRI): Provide ^{239}Pu and ^{240}Pu standards in support of AFRRI's efforts to demonstrate its ICP-MS capability of detecting ultra low-level Pu in urine samples.

Z.C. Lin, with support from PNNL-DOE: Establish resin bead method for detecting ultra low-level Pu isotopes in environmental and bioassay samples by Thermal Ionization Mass Spectrometry (TIMS).

Z.C. Lin and K.G.W. Inn, with support from EML-DOE and IRMM-EU: Evaluate the competence of alpha spectrometry analysis algorithms used to resolve the ^{241}Am and ^{243}Am alpha peak overlap.

L.L. Lucas and L.R. Karam, with support from the Nuclear Regulatory Commission: Provide traceability testing of the NRC primary quality control laboratory.

Z.Y. Wu and K.G.W. Inn, with support from Oak Ridge National Laboratory's Intercomparison Studies Program: Provide QC monitoring samples to the radiobioassay and environmental communities to assess the statistical control over routine analytical measurements. In support of ORNL's efforts to demonstrate it's own measurement traceability to NIST, the Radioactivity Group is conducting ongoing traceability evaluation studies with ORNL for radionuclides in urine and water. Furthermore, the Radioactivity Group is evaluating the calibration of ORNL's internal standards to assure the basis for accuracy of the source materials for the monitoring samples they produce for their customers.

R. Minniti, J. Shobe and S.M. Seltzer, research with the U.S. Air Force/DOD to develop low-level dosimetry traceability to national air-kerma standards.

M.P. Unterweger and L.R. Karam, with support from the U.S. Air Force: Provide measurements and calculations that determine the 2π results to activity ratios for beta particles emitted from arbitrarily thick sources plated on substrates of arbitrary atomic number.

TIME AND FREQUENCY DIVISION (847)

D.A. Howe, research for the Office of Naval Research: Development of a 100 GHz PM/AM noise measurement system.

D.A. Howe, research for the NSA: Phase Noise Measurement System.

D.A. Howe, research for U.S. Army: Low Jitter Clock.

D.A. Howe, research for USAF: Total Hadamard development.

J.P. Lowe, consulting to National Weather Service, NOAA: Broadcast of marine weather alerts on WWV and WWVH.

J.P. Lowe, consulting to the U.S. Coast Guard (Dept. of Transportation): Broadcast of status of GPS satellites on WWV and WWVH.

J.P. Lowe, consulting to the State Department regarding the NILESAT-Egypt cooperative agreement.

J. Levine, consulting to the U.S. Air Force: Development of carrier-phase time transfer methods and Rubidium clocks.

J. Levine, research for NSA: Advance Time Transfer Concepts.

T.E. Parker, consulting for the Jet Propulsion Laboratory, NASA: Time transfer to NASA sites and analysis of time transfer data.

T.E. Parker, research for NSA: Clock Synchronization Project

T.E. Parker, research and consulting for Space Division, U.S. Air Force: Analysis of GPS data and systems and consultations on GPS operating procedures.

D.B. Sullivan, research and consulting for NASA: Development of a laser-cooled-cesium clock for scientific and technical applications in space.

D.J. Wineland, consulting to Office of Naval Research (ONR): Basic research on frequency standards and study of cooled, trapped ions.

D.J. Wineland, consulting to Office of Naval Research (ONR): Research into strongly-coupled, one-component plasmas stored in electromagnetic traps.

D.J. Wineland, consulting to the National Security Agency (NSA): Research on quantum computing.

D.J. Wineland, Consulting with USAF (NRO): Research multiplexing of ion traps for quantum information processing.

D.J. Wineland and L. Hollberg, Consulting to NASA: Research on space optical frequency standard.

QUANTUM PHYSICS DIVISION (848)

E.A. Cornell, S.T. Cundiff, A.C. Gallagher, J.L. Hall, D.S. Jin, S.R. Leone, D.J. Nesbitt, and J. Ye, research for NSF in atomic and molecular physics.

E.A. Cornell, research for NSF: Demonstration of Bose-Einstein condensation in a gas.

E.A. Cornell and D.S. Jin, research for ARMY/ARO: Ultracold atom optics science and technology.

E.A. Cornell, research for Navy/ONR: Spontaneous force optical traps.

E.A. Cornell, research for Navy/ONR: Neutral atom hoses and waveguides.

S.T. Cundiff, research for W.M. Keck Foundation: Keck Optical Measurement Laboratory.

S.T. Cundiff, research for NSF: Nonlinear optical spectroscopy of mixed-valent materials.

S.T. Cundiff, research for DOE: Electronic structure and phase transitions of complex electronic oxides: Angle-resolved and pump probe photoemissions experiments.

J.E. Faller, research for NSF: Active seismic isolation for interferometric gravitational wave detectors.

A.C. Gallagher, research for NREL: Characterization of small particle formation in the preparation of amorphous silicon solar cells, and determination of the electric field profile in solar cells.

A.C. Gallagher, research for NREL: RGA Analysis of the HWCVD process.

J.L. Hall and J. Ye,, research for NASA: Widely tunable optical local oscillators with 1 E-15 stability: Ultrastable laser system for space interferometry

J.L. Hall, research for CRDF: Optical frequency standards and principal testing the new concept of a direct fs-comb bridge between the optical and microwave domains.

D.S. Jin, research for Navy/ONR: Research in exploring an ultracold gas of fermionic atoms.

D.S. Jin, research for DOE: Explore expansion toward cooper paring of fermionic atoms.

D.S. Jin, research for NSF: Research experience for undergraduates in Physics/JILA.

S.R. Leone, research for DOE: Time-resolved FTIR emission studies of laser photofragmentation and radical reactions.

S.R. Leone, research for ARMY/ARO: Kinetic-energy-enhanced neutral etching.

S.R. Leone, research for NASA: Laboratory studies of low temperature rate coefficients: the atmospheric chemistry of the outer planets.

S.R. Leone, research for AF/AFOSR: Ion dynamics related to hypersonics.

S.R. Leone, research for NSF: Investigate alignment and wave packet chemical dynamics.

S.R. Leone, research for NSF: Infrared band-specific near field optical microscopy.

S.R. Leone, research for ARMY/ARO: Ultrafast laser studies of molecular Rydberg wave.

S.R. Leone, research for AF/AFOSR: Ultrafast soft x-ray laser probing of core level molecular dynamics.

S.R. Leone, research for NSF: Phase and amplitude dynamics of rovibrational waves.

S.R. Leone, research for ARMY/ARO: Femtosecond laser regenerative amplifier for quantum information science.

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: dynamics of radicals, molecules and clusters.

D.J. Nesbitt, research for NSF: State-Resolved spectroscopy and dynamics of chemical transients.

D.J. Nesbitt, research for Outreach: CU Wizard science outreach.

J. Ye, research for ResCorp: Ultrastable optical frequencies across the entire visible spectrum and ultrahigh resolution spectroscopy using a femtosecond Laser.

J. Ye, research for CPOP: Development of highly stable solid state lasers in the 1 um to 2 um wavelength region. ❑

CALIBRATION SERVICES AND STANDARD REFERENCE MATERIALS

ELECTRON AND OPTICAL PHYSICS DIVISION (841)

CALIBRATION SERVICES PERFORMED

Type of Service	Customer Classification	SP 250	Number of Customers	Number of Tests
Far UV Detector	Industrial	40530C	1	1
Far UV Detector	University	40531C	1	1
Far UV Detector	Industrial	40561C	1	1
Far UV Detector	University	40561C	2	2
Far UV Detector	Industrial	40599S	8	8
Far UV Detector	University	40599S	1	1
Far UV Detector	Government	40599S	2	2
Far UV Detector	Foreign	40599S	3	3
Spectrometer	University	N/A	1	3
		Total	**20**	**22**

ATOMIC PHYSICS DIVISION (842)

CALIBRATION SERVICES PERFORMED

Type of Service	Customer Classification	SP 250	Number of Customers	Number of Tests
Deuterium Lamp	Industrial	40040F	1	1

OPTICAL TECHNOLOGY DIVISION (844)

CALIBRATION SERVICES PERFORMED

Type of Service	Customer Classification	SP 250	Number of Customers	Number of Tests*
Spectroradiometry Sources	Industrial	39010C through 39060S	3	37
	Instrument and Calibration Lab.[1]		7	
	Government		5	
	Foreign		3	
Spectroradiometry Detectors	Industrial	39071C through 39100C	1	86
	Instrument and Calibration Lab.[1]		19	
	Government		7	
	Foreign		3	
Photometry	Industrial	37010C through 37110S	8	75
	Instrument and Calibration Lab.[1]		11	
	Government		6	
	Foreign		1	
Optical Properties of Materials	Industrial	38010C through 39061S	8	61
	Instrument and Calibration Lab.[1]		10	
	Government		6	
	Foreign		2	
Radiance Temperature	Industrial	35010C through 35070S	6	29
	Instrument and Calibration Lab.[1]		4	
	Government		9	
*Number of lamps, detectors, optical filters or materials tested.			**119**	**288**

[1] Universities were included in Instrument and Calibration Lab classification.

OPTICAL TECHNOLOGY DIVISION (844) (Continued)

STANDARD REFERENCE MATERIALS

SRM No.	Title of SRM	Customer Classification	Calibration Supported	No. Sold
1001	X-Ray Film Step Tablet	Industrial Instrument and Cal. Lab Government Foreign	Calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields.	76
1008	Photo Step Tablet	Industrial Instrument and Cal. Lab Government Foreign	Calibration of optical densitometers in the photographic and graphic arts.	32
1010A	Microcopy Test Chart	Industrial Instrument and Cal. Lab Government Foreign	For determining the resolving power of microcopy systems. It meets all the requirements for ISO Test Chart No. 2.	51
1920A	Near IR Reflectance	Industrial Instrument and Cal. Lab Government Foreign	For establishing the accuracy of the wavelength scale of reflectance spectrophotometers or reflectometers using hemisphericial geometry	14
1921A	IR Transmission Wavelength	Industrial Instrument and Cal. Lab Government Foreign	Calibration of infrared spectrophotometers	208
2003	First Surface Aluminum Mirror	Industrial Instrument and Cal. Lab Government Foreign	Calibration of photometric scale of specular reflectometers	8
2011	First Surface Gold Mirror	Industrial, Instrument and Calibration Lab., Government, and Foreign	Calibration of reflectance scales of specular reflectometers	2
2023	Second Surface Aluminum Mirror	Industrial, Instrument and Calibration Lab., Government, and Foreign	Calibration of photometric scale of specular reflectometers	4
2026	First Surface Black Glass	Industrial, Instrument and Calibration Lab., Government, and Foreign	Calibration of photometric scale of specular reflectometers	2
2046-2056	Transmission Filters	Industrial Instrument and Cal. Lab Government Foreign	Calibration of transmittance measurements using lasers or infrared spectrophotometers; for attenuating the optical power 1064 nm; and for characterizing the nonlinearity of detection systems.	3
		Total		**400**

IONIZING RADIATION DIVISION (846)
Radiation Interactions and Dosimetry Group

CALIBRATION SERVICES PERFORMED

Dosimetry of X Rays, Gamma Rays, and Electrons

Type of Service	Customer Classification	SP 250	Number of Customers	Number of Tests
X-ray and Gamma-ray Measuring	Industrial	46010C	10	30
		46011C		18
	Government	46010C	8	24
		46011C		63
	Foreign	46010C	1	1
Passive Dosimeters	Industrial	46020C	2	5
		46021C		37
Gamma-ray Sources and Measuring Instruments	Medical	47010C	15	29
		47011C		79
Beta Instruments	Government	47035C	1	3
	Total		**37**	**289**

High-Dose Calibration Services Performed

Type of Service	Customer Classification	SP 250	Number of Customers	Number of Tests*
Supply Transfer Dosimeters	Industrial	49020C	11	11
		49030C	9	65
	Foreign	49020C	1	1
Irradiate Dosimeters	Industrial	49010C	24	179
	Government	49010C	1	22
	Foreign	49010C	1	11
	Total		**47**	**289**

* Number of radiation sources and detectors tested

IONIZING RADIATION DIVISION (846) (Continued)
Neutron Interactions and Dosimetry Group

CALIBRATION SERVICES PERFORMED

Type of Service	Customer Classification	SP 250	Number of Customers	Number of Tests*
Radioactive Neutron Source	Industrial	44010C	1	1
	Government	44010C	2	3
Neutron Survey Instrument	Industrial	44060C	6	7
	Government	44060C	1	1
	Total		**10**	**12**

Radioactivity Group

CALIBRATION SERVICES PERFORMED

Type of Service	Customer Classification	SP 250	Number of Customers	Number of Tests
Activity Measurement	Instrument and Calibration Laboratory	43030C	1	14
		43090S	1	14
Activity Measurement	Government	43030C	3	11
		43090S	1	2
Activity Measurement	Industrial	43010C	1	2
		43030C	2	3
	Totals		**9**	**46**

IONIZING RADIATION DIVISION (846) (Continued)
Radioactivity Group (Continued)

STANDARD REFERENCE MATERIALS

SRM No.	Title of SRM	Calibration Supported	No. Sold
4201B	Nb-94 (point source)	Gamma spectrometry	1
4203D	Co-60 (point source)	Gamma spectrometry	6
4218F	Eu-152 (point source)	Gamma spectrometry	3
4222C	C-14 hexadecane	Liquid scintillation	5
4226C	Ni-63 solution	Liquid scintillation	4
4234A	Sr-90 solution	Liquid scintillation	2
4241C	Ba-133 (point source)	Gamma spectrometry	2
4251C	Ba-133 solution	Gamma spectrometry	2
4288A	Tc-99 solution	Environmental	8
4320A	Cm-244 solution	Environmental	5
4321C	U-natural solution	Environmental	25
4322B	Am-241 solution	Environmental	6
4323B	Pu-238 solution	Environmental	5
4325	Be-9/10 solution	Geological dating	4
4326	Po-209 solution	Environmental	10
4328B	Th-229 solution	Environmental	37
4330B	Pu-239 solution	Environmental	11
4332D	Am-243 solution	Environmental	23
4334G	Pu-242 solution	Environmental	67
4338A	Pu-240 solution	Environmental	3
4340A	Pu-241 solution	Environmental	12
4341	Np-237 solution	Environmental	7
4342	Th-230 solution	Environmental	2
4350B	River sediment	Environmental	9
4351	Human Lung powder	Environmental	1
4354	Lake sediment	Environmental	8
4355	Peruvian soil	Environmental	8
4356	Ashed bone	Environmental	18
4357	Ocean sediment	Environmental	13

IONIZING RADIATION DIVISION (846) (Continued)

STANDARD REFERENCE MATERIALS (Continued)

SRM No.	Title of SRM	Calibration Supported	No. Sold
4361C	H-3 water	Hydrology	6
4370C	Eu-152 solution	Gamma spectrometry	2
4401H	I-131 solution	Radiopharmaceutical	6
4401L	I-131 solution	Radiopharmaceutical	13
4404H	Tl-201 solution	Radiopharmaceutical	9
4404L	Tl-201 solution	Radiopharmaceutical	4
4407H	I-125 solution	Radiopharmaceutical	10
4407L	I-125 solution	Radiopharmaceutical	17
4410H	Tc-99m solution	Radiopharmaceutical	12
4412H	Mo-99 solution	Radiopharmaceutical	5
4412L	Mo-99 solution	Radiopharmaceutical	6
4415H	Xe-133 gas	Radiopharmaceutical	4
4415L	Xe-133 gas	Radiopharmaceutical	6
4416H	Ga-67 solution	Radiopharmaceutical	5
4416L	Ga-67 solution	Radiopharmaceutical	5
4417H	In-111 solution	Radiopharmaceutical	6
4417L	In-111 solution	Radiopharmaceutical	6
4425H	Sm-153 solution	Radiopharmaceutical	4
4425L	Sm-153 solution	Radiopharmaceutical	5
4427H	Y-90 solution	Radiopharmaceutical	6
4427L	Y-90 solution	Radiopharmaceutical	6
4915E	Co-60 solution	Gamma spectrometry	1
4919H	Sr-90 solution	Environmental and liquid scintillation	10
4926E	H-3 water	Hydrology and liquid scintillation	14
4915E	Co-60 solution	Gamma spectrometry	1
4919H	Sr-90 solution	Environmental and liquid scintillation	10
4926E	H-3 water	Hydrology and liquid scintillation	14
4927F	H-3 water	Hydrology and liquid scintillation	19
4947C	H-3 toluene	Liquid scintillation	4
4949C	I-129 solution	Environmental	6

IONIZING RADIATION DIVISION (846) (Continued)

STANDARD REFERENCE MATERIALS (Continued)

SRM No.	Title of SRM	Calibration Supported	No. Sold
4966	Ra-226 solution	Environmental	10
4967	Ra-226 solution	Environmental	8
4968	Rn-222 capsule	Environmental	7
4969	Ra-226 solution	Environmental	3
4990C	Oxalic acid powder	Carbon-14 dating	22
		Total	**554**

Customers Classification	No. Sold
Public	192
Government (Federal, State, Local, and NIST)	216
Foreign Government	146
Total	**554**

TIME AND FREQUENCY DIVISION (847)

CALIBRATION SERVICES PERFORMED

Type of Service	Customers Classification	SP 250	Number of Customers	Number of Tests
Frequency Measurement Service	Industrial	76100S	29	504
	Government		13	
	Foreign		6	
Global Time Service	Industrial	76110S	8	132
	Government		2	
	Foreign		2	
Charac. of Oscillators	Industrial	77100C	5	5
	Total		**65**	**641** ❑

ACRONYMS & ABBREVIATIONS

AAPM	American Association of Physicists in Medicine
ACRii	absolute cryogenic radiometer (second upgrade)
ACTS	Automated Computer Time Service
ADCL	Accredited Dosimetry Calibration Laboratories
ADMIT	analytical detection methods for the irradiation treatment of foods
AEDC	Arnold Engineering Development Center
AFGL	Air Force Geophysics Laboratory
AFM	atomic force microscope
AFOSR	Air Force Office of Scientific Research
AFRRI	Armed Forces Radiobiology Research Institute
AI	associative ionization
AIAA	American Institute for Aeronautics and Astronautics
AIP	American Institute of Physics
AIChE	American Institute of Chemical Engineering
AM	amplitude modulation
AM1	First launch in the morning series of EOS platforms
AML	Advanced Measurement Laboratory
AMO	Atomic, Molecular and Optical
AMS	accelerator-mass-spectrometry
ANS	American Nuclear Society
ANSI	American National Standards Institute
ANSOM	Apertureless Near-field Scanning Optical Microscopy
APAS	Astrophysical, Planetary and Atmospheric Sciences
APOMA	American Precision Optics Manufacturers Association
APS	American Physical Society
APS	Advanced Photon Source
ARDA	Advance Research and Development Activity
ARO	Army Research Office
ART	algebraic reconstruction technique
ASQ	American Society of Quality
ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer
ASTM	American Society for Testing and Materials
AT&T	Atlantic Telephone & Telegraph
ATI	above-threshold ionization
ATP	Advanced Technology Program
AURA	Association of Universities for Research in Astronomy
AXAF-I	Imaging Advanced X-ray Astrophysical Facility
BARC	Bhabha Atomic Research Centre
BBIR	broad-band infrared
BBXRT	Broad-Band X-Ray Telescope
BCC	broad-band calibration chamber
BEB	Binary-Encounter-Bethe
BEC	Bose-Einstein Condensation
BED	Binary-Encounter-Dipole
BEV	Bundesamt für Eich-und Vermessungswesen, Vienna, Austria
BFRL	Building and Fire Research Laboratory
BGSM	Bowman Gray School of Medicine
BIFL	burst integrated fluorescence
BIPM	Bureau International des Poids et Mésures
BL	beamline at SURF
BMDO	Ballistic Missile Defense Organization
BNL	Brookhaven National Laboratory
BRAN	Boulder Regional Area Network

BRDF	bidirectional reflectance distribution function
BSA	bovine serum albumin
BSDF	bidirectional scattering distribution function
BSS	beta secondary standard
BSS2	beta secondary standard 2nd
BWO	backward wave oscillators
BXR	BMDO transfer radiometer
CAD	computer aided design
CAMOS	Committee on Atomic, Molecular and Optical Sciences
CARS	Coherent Anti-Stokes Raman Spectroscopy
CAST	Council of Agricultural Science and Technology
CCD	charged coupled device
CCE	Consultative Committee on Electricity
CCG	Calibration Coordination Group
CCL	Consultative Committee on Length
CEOS	Committee on Earth Observing Satellites
CCPR	Consultative Committee on Photometry and Radiometry
CCRI	Comité Consultatif pour Rayonnements Ionisants
CCTF	Consultative Committee for Time and Frequency
CEL	correlated emission laser
CFS	constant-final-state spectroscopy
CGSIC	Civilian GPS Service Interface Committee
CIAQ	Committee on Indoor Air Quality
CIE	Commission Internationale De L'Eclairage
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
CIPM	International Committee of Weights and Measures
CIRMS	Council on Ionizing Radiation Measurements and Standards
CIRRPC	Committee on Interagency Radiation Research and Policy Coordination
CLEO	Conference on Lasers and Electro-Optics
CMC	calibration measurement capabilities
CNIF	Californium Neutron Irradiation Facility
CODATA	Committee on Data for Science and Technology
CORM	Council for Optical Radiation Measurements
COSPAR	Committee on Space Research
COTR	Contracting Office Technical Representative
CPEM	Conference on Precision Electro-magnetic Measurements
CPOP	Colorado Photonics and Optoelec-tronics Program
CPU	central processing unit
CR	cascaded rectifier accelerator
CRADA	Cooperative Research and Development Agreement
CRCPD	Conference of Radiation Control Program Directors
CRI	Cambridge Research Insturmentation
CRP	Coordinated Research Program
CRYRING	Institute in Stockholm
CSEWG	Cross Section Evaluation Working Group
CSI	Compton scatter imaging
CSIC	Consejo Superior de Investigaciones Cientificas
CSRA-REMP	Central Savannah River Area – Radiological Environmental Monitoring Programs
CSTL	Chemical Science and Technology Laboratory
CT	computed tomography
CTI	Critical Technologies Institute
CVD	chemical vapor deposition
cw (CW)	continuous wave
DAMOP	Division of Atomic Molecular and Optical Physics
DARPA	Defense Advanced Research Project Agency

DMA	Defense Mapping Agency
DMMP	dimethylmethylphosphonate
DNA	Defense Nuclear Agency
DNA	deoxyribose nucleic acid
DoC (DOC)	U.S. Department of Commerce
DoD (DOD)	U.S. Department of Defense
DoE (DOE)	U.S. Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
DOTMP	1,4,7,10-tetraazacyclododecane - 1,4,7,10 tetramethylenephosphonic acid
DRAM	dynamic random access memory
DSA	digital subtraction angiography
DSC	differential scattering cross-section
DUT	device under test
DUV	deep-ultraviolet
DVM	digital voltmeter
EBIS	Electron Beam Ion Source
EBIT	Electron Beam Ion Trap
ec	electron-capture
ECP	effective core potential
ECR	electron cyclotron resonance
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
EEP	Einstein Equivalence Principle
EID	excitation induced dephasing
EIS	excitation induced shift
EML (EM)	Environmental Management Laboratory
ENEA	Ente Per Le Nuove Tecnologie, L'Energia E L'Ambiente
ENDL	Evaluated Nuclear Data Library
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPG	Electron Physics Group
EPIC	Earth Polychromatic Imaging Camera
EPR	electron paramagnetic resonance
EPRI	Electric Power Research Institute
ERATO	Exploratory Research for Advanced Technology Office
ESA	European Space Agency
ESDIAD	electron-stimulated desorption ion angular distributions
ESR	electron spin resonance (EPR now preferred)
ESR	electrical substitution radiometer
ESR	experimental storage ring
ETRAN	electron transmission computer code
EU	European Union
EURATOM	European nuclear energy organization
EUV	extreme ultraviolet
EUVE	Extreme Ultraviolet Explorer
EUV-LLC	Consortium of Intel, Motorola, AMD, Micron Technology, Infineon Technologies, and IBM
FAA	Federal Aviation Administration
FAD	FASCAL accurate detector
FAMOS	Future of Atomic Molecular and Optical Science
FASCAL	Facility for Automatic Spectro-radiometric Calibrations
FCDC	Fundamental Constants Data Center
FDA	Food and Drug Administration
FEDS	field-emitter displays
FEMA	Federal Emergency Management Agency
FIMS	fissionable isotope mass standards
FLIR	forward looking infrared radiometer
FNR	Ford Nuclear Reactor
FOS	Faint Object Spectrograph
FOV	field of view
FRET	fluorescence resonant energy transfer
FT	Fourier Transform
FTIR	Fourier Transform Infrared

FT-IRAS	Fourier Transform-Infrared Reflection Absorption Spectroscopy
FTMS	Fourier Transform Microwave Spectroscopy
FTMW	Fourier Transform Microwave
FTS	Fourier Transform Spectroscopy
FUV	far ultraviolet
FY	fiscal year
GAMS 4	NIST high resolution spectrometer
GE	General Electric
GEC	Gaseous Electronics Conference
GFP	green fluorescent protein
GIAC	GPS Interagency Advisory Council
GIM	grazing-incidence monochromator
GLONASS	Global Navigation Satellite System
GMR	giant magnetoresistance
GOES	Geostationary Operational Environmental Satellite
GPIB	general purpose instrumentation bus
GPS	Global Positioning System
GRI	Gas Research Institute
GSFC	Goddard Space Flight Center
GSI	Gessellschaft f. Schwerionenforschung
GUI	graphical user interface
GVHD	graft-versus host disease
HACR	high accuracy cryogenic radiometer
HBM	hybird bilayer membranes
HDR	high dose rate
HECT	high energy computed tomography
HFS (hfs)	hyperfine structure
HFIR	High Flux Isotope Reactor
HID	high intensity discharge
HIRDLS	High Resolution Dynamics Limb Sounder
HPS	Health Physics Society
HR	high resolution
HR3DCT	high resolution 3-D computed tomography
HSST	heavy section steel technology
HTBB	high-temperature black body
HTD	Heat Transfer Division
HTML	hypertext markup language
HTS	high-temperature superconductivity
HVL	half-value layer
HWCVD	hot-wire chemical vapor deposition
IAEA	International Atomic Energy Agency
IAG	International Association of Gravity
IBM	International Business Machines
ICAMDATA	International Conference on Atomic and Molecular Data
ICAP	International Conference on Atomic Physics
ICOLS	International Conference on Laser Spectroscopy
ICP	inductively coupled plasma
ICPEAC	International Conference on the Physics of Electronic and Atomic Collisions
ICQI	International Conference on Quantum Information
ICRM	International Committee for Radionuclide Metrology
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
ID	inside diameter
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEN	Istituto Elettrotecnico Nazionale (Italy)
IESNA	Illumination Engineering Society of North America
IHPRPTP	Integrated High Payoff Rocket Propulsion Technology Program
ILL	Institut Laue Langevin
ILS	International Laser Spectroscopy
IMC	isothermal microcalorimeter
IMECE	International Mechanical Engineering Congress and Exposition

IMS	Institute for Molecular Science
INFM	National Institute for the Physics of Matter
INISO-TTC	experimental radiochromic film
INM	Institute National de Metrologie
INMM	Institute for Nuclear Materials Management
INTERNET	International Computer Network
IPNS	intense pulsed neutron source
IPSN	Institut de Protection et de Sureté Nucleairé
IQEC	International Quantum Electronics Conference
IR	infrared
IRB	Institutional Review Board
IRD	International Radiation Detectors
IRDCF	Infrared Detector Calibration Facility
IRMM	Institute of Reference Materials and Measurements
ISCC	Inter-Society Color Council
ISO	International Organization for Standardization
ISSC	information system to support calibrations
ISS	International Space Station
ITAMP	International Meeting of Theoretical Atomic and Molecular Physics
ITL	Information Technology Laboratory
ITT	thermal infrared transfer radiometer
ITU	International Telecommunication Union
IU	Indiana University
IUE	International Ultraviolet Explorer
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
IWG	Investigators Working Group
JANNAF	Joint-Army-Navy-NASA-Air Force
JCGM	Joint Committee for Guides on Metrology
JCMT	James Clerk Maxwell Telescope
JHU	Johns Hopkins University
JILA	formerly Joint Institute for Laboratory Astrophysics
JPL	Jet Propulsion Laboratory
KCDB	key comparison and calibration database
LAGOS	Laser Gravitational-Wave Observatory in Space
LAMSCAL	large area monochromatic source for calibrations
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Scattering Center
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
LET	linear energy transfer
LIF	laser induced fluorescence
LIGO	Laser Interferometric Gravitational-Wave Observatory
LLNL	Lawrence Livermore National Laboratory
LMRI	French Laboratories de Measure des Rayonnements Ionisants
LORAN-C	radio navigation system operated by the U.S. Coast Guard
LPRI	Laboratoire Primaire des Rayonnements Ionisants, Gif-sur-Yvette, France
LPRT	light-pipe radiation thermometers
LPTF	Primary Laboratory for Time and Frequency, [Laboratoire Primaire du Temps et Fréquences (France)]
LS	liquid scintillation
LSC	liquid scintillation counting
LT	low-temperature
LTE	local thermodynamic equilibrium
LTEC	Lamp Testing Engineers Conference
LTG	low-temperature-growth
LWIR	long wave infrared

MARLAP	Multi-Agency Radiological Laboratory Procedures
MARS	multiple-angle reference system
MBE	molecular beam epitaxy
MBIR	Medium Background Infrared Facility
MCNP	Monte Carlo Neutron Photon (computer code)
MCT	mercury-cadmium-telluride
MDRF	Materials Dosimetry Reference Facility
MEDEA	microelectronics development for European applications
MEL	Manufacturing Engineering Laboratory
MEMS	micro-electro-mechanical systems
MET	Medium Energy Telescope
MIL	military
MIRD	Medical Internal Radiation Dose (committee)
MIRF	Medical and Industrial Radiation Facility
MISR	multi-angle imaging spectro-radiometer
MIT	Massachusetts Institute of Technology
MJD	modified Julian date
MOBE	modified optical Bloch equations
MOBY	Marine Optical Buoy
MODIL	Manufacturing Operations Development & Integration Laboratory
MODIS	Moderate Resolution Imaging Spectrometer
MOEMS	micro-opto-electro-mechanical systems
MOPITT	measurement of pollution in the troposphere
MOS	Marine Optical System
MOS	Marine Optical Spectrograph
MOS	metal oxide semiconductors
MOSFET	metal oxide semiconductor field effect transistor
MOT	magneto optical trap
MQDT	Multichannel Quantum Defect Theory
MPI	multiphoton ionization
MQA	Measurement Quality Assurance
MQSA	Mammography Quality Standards Act
MRA	Mutual Recognition Arrangement
MRI	magnetic resonance imaging
MSEL	Materials Science and Engineering Laboratory
MSC	Measurement Science Conference
MTG	methanol to gasoline
MURI	Multidisciplinary University Research Initiative
MW	microwave
NAMP	National Analytical Management Program
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	NIST Beowulf System
NBSR	National Bureau of Standards' Reactor (retains the NBS name)
NCI	National Cancer Institute
NCNR	NIST Center for Neutron Research
NCRP	National Council on Radiation Protection and Measurements
NCSL	National Conference of Standards Laboratories
NDE	non-destructive evaluation
NDT	nondestructive testing
Nd:YAG	Neodymium: Yttrium Aluminum Garnet (YAG doped with Nd)
NEANDC	Nuclear Energy Agency Nuclear Data Committee
NEANSC	Nuclear Energy Agency Nuclear Science Committee
NEC	Nippon Electric Corporation
NEI	Nuclear Energy Institute

NEOS	Newport Electro-Optic Systems
NERI	Nuclear Energy Research Initiative
NESDIS	Environmental Satellite Data and Information Service
NEWRAD	New Radiometry
NG6	neutron guide no. 6
NGS	National Geological Society
NI&D (NID)	Nuclear Interactions and Dosimetry
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
NIST	National Institute of Standards and Technology
NIST-7	former NIST primary frequency standard
NIST-F1	current NIST primary frequency standard
NISTIR	NIST Internal Report
NISTAR	NIST Advanced Radiometer
NMI	National Measurement Institute
NMI	National Metrology Institute
NML	National Measurement Laboratory (Japan)
NMS	natural matrix standard
NNI	National Nanotechnology Initiative
NOAA	National Oceanographic and Atomospheric 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	North American regional collaboration in national measurement standards and services
NPL	National Physical Laboratory (U.K.)
NPOESS	National Polar-orbiting Operational Environmental Satellite
NPP	NPOESS Preparatory Project
NPSS	Nuclear and Plasma Sciences Society
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NRIP	NIST Radiochemistry Intercomparison Program
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NRRS	near resonance rayleigh scattering
NSA	National Security Agency
NSBP	National Society of Black Physicists
NSF	National Science Foundation
NSOM	near-field scanning optical microscopy
NSTC	National Science and Technology Council
NTS	network time service
NVIS	night vision imaging system
NVLAP	National Voluntary Laboratory Accreditation Program
NYSTAR	New York Scientific, Technical and Academic Research
OAI	Optical Associates, Inc.
OD	optical density
OFS	Österreichisches Forschungszentrum
OIDA	Optoelectronics Industry Development Association
OIML	International Organization of Legal Metrology
OMB	Office of Management and Budget
OMEGA	24-Beam Laser Facility at Rochester
OMH	National Office of Measures (Hungary)
OMP	Office of Manufacturing Partnerships
ONR	Office of Naval Research
OP	optical properties
OPO	optical parametric oscillator
ORM	Office of Radiation Measurement
ORNL	Oak Ridge National Laboratory

OSA	Optical Society of America
OSEP	Optical Science and Engineering Program
OSL	optical stimulated luminescence
OSTP	Office of Science and Technology Policy
OTD	Optical Technology Division
PA	proton affinity
PARCS	Primary Atomic Reference Clock in Space
PC	personal computer
PCB	polychlorinated biphenyls
PDML	Photovoltaic Device Measurement Laboratory
PE	performance evaluation
PECVD	plasma-enhanced chemical vapor deposition
PET	positron emission tomography
PID	proportional, integral, and derivative (a type of servo system)
PL	Physics Laboratory
PM	phase modulation
PMG	Precision Measurement Grant
PMMA	polymethylmethacrylate
PMT	photomultiplier tube
PNNL	Pacific Northwest National Laboratory
POC	Physical Optics Corporation
POP	plasma oscillation probe
POPA	Panel on Public Affairs of American Physical Society
PRF	Petroleum Research Fund
PRM	precision radiation measurement
PSD	photon-stimulated desorption
PSL	polystyrene-latex
PT	performance testing
PTB	Physikalisch-Technische Bundesanstalt (Germany)
PTCA	percutaneous transluminal coronary angioplasty
PTI	Proxima Therapeutics, Inc.
PWR	pressurized-water reactor
PZT	piezoelectric transducer
QCD	quantum chromodynamics
QED	quantum electrodynamics
QELS	Quantum Electronics and Laser Science
QMD	Quantum Metrology Division
RAC	Research Advisory Committee
RBS	Rutherford backscattering
R&D	research and development
RDP	rubidium di-hydrogen phosphate
RF (rf)	radio frequency
RGA	residual gas analyzer
RIMS	resonance ionization mass spectrometry
RMO	Regional Metrology Organization
RNA	ribonucleic acid
ROSPEC	Rotating Spectrometer for Neutrons
RTC	Radiochromic Film Task Group
RTP	rapid thermal processing
SAM's	self-assembled monolayers
SANS	small-angle neutron scattering
SBIR	Small Business Innovation Research
SCATMECH	A computer program
SCC	spectral calibration chamber
SCC	Standards Coordinating Committee
SCLIR	Secondary Calibration Laboratories for Ionizing Radiation
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SDL/USU	Space Dynamics Laboratory/Utah State University
SEBA	Standards' Employees Benefit Association
SEMATECH	consortium of 14 U.S. semiconductor manufacturers
SEMPA	scanning electron microscopy with polarization analysis
SFA	Sachs Freeman and Associates
SFG	sum frequency generation

SI	Système International d' Unités *or* International System of Units
SIA	Semiconductor Industry Association
SID	Society for Information Display
SIMS	secondary ion mass spectrometry
SIRCUS	spectral irradiance and radiance calibration with uniform sources
SIRREX-3	SeaWifs intercalibration round-robin experiment
SLCO	sapphire loaded cavity oscillator
SLMs	synthetic layer microstructures
SM	single molecule
SME	Solar Mesosphere Explorer
SNS	spallation neutron source
SOG	spin-on glass
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SP	special publication
SPIE	Society of Photo-optical Instrumentation Engineers
SPP	storage photostimulable phosphor
SPS	Society for Physics Students
SQL	structured query language
SRAM	static random access memory
SRD	standard reference data
SRM	standard reference material
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSDL	Secondary Standard Dosimetry Laboratory
SSRCR	state suggested regulations for controlling ionizing radiations
SSUV	Shuttle Solar Ultraviolet
STARR	spectral tri-function automated reference reflectometer
STD	standard
STM	Scanning Tunneling Microscope
STP	standard temperature and pressure
SUNY	State University of New York
SURF	Synchrotron Ultraviolet Radiation Facility (SURF II, second upgrade *or* SURF III, third upgrade)
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SVGL	Silicon Valley Group Lithography
SWIR	short wave infrared
SXR	SeaWiFS transfer radiometer
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
TEMPMEKO	Temperature and Thermal Measurements in Industry and Science
TEXT	Texas Experimental Tokamak
TFWM	transient four-wave-mixing
TG	technical group
TGM	toroidal-grating monochromator
TIGER	Thermospheric, Ionospheric, and Geospheric Research
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIMS	thermal ionization mass spectrometry
TLC	thin layer chromatography
TMA	tri-methyl-aluminum
TOMS	Total Ozone Mapping Spectrometer
TQM	total quality management
TuFIR	tunable far infrared (radiation)
UA	University of Arizona
UCN	ultra cold neutron
UHV	ultrahigh vacuum
UK	United Kingdom
UOU	University of Utah
UPS	ultraviolet photoelectron spectroscopy
URL	uniform resource locator
USA	United States of America
USAF	U.S. Air Force
USCEA	U.S. Council for Energy Awareness
USDA	U.S. Department of Agriculture

USFDA	U.S. Food and Drug Administration
USNA	U.S. Naval Academy
USNC	U.S. National Committee
USNO	U.S. Naval Observatory
UTC	coordinated universal time
UV	ultraviolet
UV-B (UVB)	ultraviolet-B
VCSEL	vertical-cavity surface-emitting laser
VEEL	vibrational and electronic energy levels
VLA	very large array
VLBI	very long baseline interferometer (*or* interferometry)
VNIIM	Mendeleyev Institute of Metrology
XPS	x-ray photoelectron spectroscopy
VRML	virtual reality markup language
VR-SFG	vibrationally resonant sum-frequency generation
VUV	vacuum ultraviolet
VXR	visible transfer radiometer
WAFAC	wide-angle free-air chamber
WDM	wave-division multiplexing
WERB	Washington Editorial Review Board
WG	working group
WKB	Wentzel-Kramers-Brillouin
WPMA	working party on measurement activities
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 (also www)
XML	extensible markup language
XROI	x-ray optical interferometer
XTE/PCA	x-ray timing explorer/proportional counter array
YAEL	Yankee Atomic Environmental Laboratory
YAG	yttrium-aluminum-garnet
YBCO	yttriuium-barium-cuprate ❑

2001 EVALUATION PANEL FOR THE PHYSICS LABORATORY

Dr. Janet S. Fender, Chair (2002)
Chief Scientist
Space Vehicles Directorate
Air Force Research Laboratory
3550 Aberdeen SE
Kirtland AFB, NM 87117-5776
505/846-2604/FAX 505/846-6689
janet.fender@kirtland.af.mil

Dr. Duncan T. Moore, Vice Chair (2004)
Rudolf & Hilda Kingslake Professor of Optical Engineering
University of Rochester
The Institute of Optics
Rochester, NY 14627-0186
716/275-5248/FAX 716/473-6745
moore@optics.rochester.edu

Dr. Patricia A. Baisden (2003)
Deputy Associate Director for Science and Technology
Lawrence Livermore National Laboratory
7000 East Avenue, L-090
Livermore, CA 94551
925/422-6661/FAX 925/422-2979
baisden1@llnl.gov

Mr. Anthony J. Berejka (2002)
Consultant
Four Watch Way
Huntington, NY 11743
Phone and FAX: 631/549-8517
berejka@msn.com

Dr. John H. Bruning (2004)
President and CEO
Corning Tropel Corporation
60 O'Connor Road
Fairport, NY 14450
716/388-3400/FAX 716/377-1966
bruningjh@corning.com

Dr. John F. Dicello (2004)
Director of Medical Physics
Johns Hopkins University
Johns Hopkins Oncology Center
Room B1-170
600 North Wolfe Street
Baltimore, MD 21287
410/614-4194/FAX 410/955-3691
diceljo@jhmi.edu

Dr. Jay M. Eastman (2002)
President & CEO
Lucid, Inc.
50 Methodist Hill Drive
Rochester, NY 14623
716/359-7260/FAX 716/359-3866
jme@lucid-tech.com

Dr. Stephen D. Fantone (2002)
President, Optikos Corporation
286 Cardinal Medeiros Avenue
Cambridge, MA 02141
617/354-7557/FAX 617/354-5946
sfantone@optikos.com

Prof. Thomas F. Gallagher (2002)
Jesse W. Beams Professor of Physics
University of Virginia
Jesse Beams Laboratory
P.O. Box 400714
Charlottesville, VA 22904-4714
804/924-6817/FAX 804/924-4576
tfg@virginia.edu

Dr. R. Michael Garvey (2004)
Chief Technical Officer
Datum Timing, Test and Measurement Inc.
34 Tozer Road
Beverly, MA 01915-5510
978-927-8220 x148
rmgarvey@datum.com

Prof. Lene Vestergaard Hau (2004)
Gordon McKay Professor of Applied Physics and Professor of Physics
Harvard University
Physics Department
Lyman Laboratory 223
Cambridge, MA 02138
617/496-5967; alternate phone: 617/497-4649
FAX 617/496-5144
hau@physics.harvard.edu

Dr. Tony F. Heinz (2003)
Department of Physics
Columbia University
538 W. 120th Street
New York, NY 10027
212/854-6564/FAX 212/854-1909
tony.heinz@columbia.edu

Dr. Jan F. Herbst (2003)
Principal Research Scientist and Manager Advanced Functional Materials Group
GM Research & Development Center
30500 Mound Road
Mail Code 480-106-224
Warren, MI 48090-9055
810/986-0580/FAX 810/986-3091
jan.f.herbst@gm.com

Prof. Franz J. Himpsel (2003)
Ednor M. Rowe Professor of Physics
Department of Physics
University of Wisconsin
B317 Sterling Hall
1150 University Avenue
Madison, WI 53706-1390
608/263-5590/FAX 608/265-2334
fhimpsel@facstaff.wisc.edu

Dr. David S. Leckrone (2003)
Senior Project Scientist
Hubble Space Telescope Project
Goddard Space Flight Center, NASA
Building 7, Room 281
Mailstop 440.0
Greenbelt, MD 20771
301/286-5975
dleckrone@hst.nasa.gov

Dr. Dennis M. Mills (2004)
Division Director, User Program Division
Advanced Photon Source
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
630/252-5680/FAX 630/252-3222
dmm@aps.anl.gov

Dr. James M. Palmer (2004)
Research Professor
The University of Arizona
Optical Sciences Center
1630 E. University Blvd.
Tucson, AZ 85721-0094
520/621-1010/FAX 520/621-3389
jmpalmer@u.arizona.edu

Dr. William N. Partlo (2004)
Vice President of Research
Cymer, Inc.
16750 Via Del Campo Court
San Diego, CA 92127-1712
858/385-6265/FAX 858/385-5353
bpartlo@cymer.com

Prof. Thad G. Walker (2003)
Physics Department
University of Wisconsin-Madison
2531 Sterling
1150 University Avenue
Madison, WI 53706
608/262-4093/FAX 608/265-2334
tgwalker@facstaff.wisc.edu

Prof. Frank W. Wise (2003)
Applied and Engineering Physics
Cornell University
252 Clark Hall
Ithaca, NY 14853
607/255-1184
fww1@cornell.edu

SUBPANEL FOR JILA

Dr. Frances A. Houle (2002)
Member, Research Staff
Almaden Res. Center
IBM Corporation
650 Harry Road K17/D1
San Jose, CA 95120-6099
408/927-2420/FAX 408/927-2510
houle@almaden.ibm.com

Prof. Dmitry Budker (2004)
Associate Professor of Physics
University of California at Berkeley
Room 219 Birge, # 7300
Berkeley, CA 94720-7300
510/643-1829
budker@socrates.berkeley.edu

Prof. Robert L. Byer (2004)
Professor
Stanford University
Edward L. Ginzton Laboratory
Director, Hansen Experimental Physics Laboratory
Chair, Department of Applied Physics
Stanford, CA 94305-4085
650/723 0226/FAX 650/723 2666
byer@stanford.edu

Prof. A. Welford Castleman, Jr. (2004)
Eberly Distinguished Chair in Science
Evan Pugh Professor
Penn State University
Departments of Chemistry and Physics
152 Davey Laboratory
University Park, PA 16802
814/865-7242/FAX 814-865-5235
AWC@psu.edu

Dr. Richard J. Colton (2004)
Supervisory Research Chemist and Head
Surface Chemistry Branch
Naval Research Laboratory
Code 6170
Washington, DC 20375-5342
202/767-0801/FAX 202/767-3321
richard.colton@nrl.navy.mil

Prof. Mark A. Kasevich (2002)
Professor of Physics
Physics Department
Sloane Physics Laboratory
Yale University
P.O. Box 208120
New Haven, CT 06520-8120
203/432-3826/FAX 203/432-9710
mark.kasevich@yale.edu

Prof. Michael D. Morse (2004)
Department of Chemistry
University of Utah
315 S. 1400 East Rm 2020
Salt Lake City, UT 84112-0850
801/581-8319/FAX 801/587-9919
morse@chemistry.utah.edu

Prof. Douglas O. Richstone (2004)
Professor and Chair
University of Michigan
Department of Astronomy
Ann Arbor, MI 48109-1090
734/764-3440/FAX 734/763-6317
dor@umich.edu

Prof. Ian A. Walmsley (2002)
Professor of Experimental Physics
University of Oxford
Department of Atomic and Laser Physics
Clarendon Laboratory
Parks Rd
Oxford OA1 3PU, United Kingdom
+44 1865 272 254/FAX +44 1865 272 375
walmsley@optics.rochester.edu