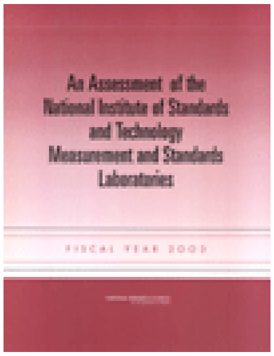

An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2003

Board on Assessment of NIST Programs, National Research Council

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An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories

FISCAL YEAR 2003

Board on Assessment of NIST Programs
Division on Engineering and Physical Sciences

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This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Marylyn Hoy Bennett, International SEMATECH,
William B. Bridges, California Institute of Technology (Emeritus),
Francois J. Castaing, Castaing & Associates,
Gregory R. Choppin, Florida State University,
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John F. O'Hanlon, University of Arizona,
Kozo Saito, University of Kentucky, and
Julia R. Weertman, Northwestern University.

Although the individuals listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of

the report before its release. The review of this report was overseen by Norman Hackerman, of the Robert A. Welch Foundation. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring board and the institution.

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Overall Assessment

This part of the report presents the Board's synopsis of the 2003 assessment, followed by its overall assessment of the NIST Measurement and Standards Laboratories. Part II provides a laboratory-level assessment of each individual laboratory. Part III presents a technical review at the division level for each laboratory.

Synopsis of the 2003 Assessment

Chapter 1
The State of the Laboratories

Synopsis of the 2003 Assessment

This report, the 2003 assessment of the Measurement and Standards Laboratories (MSL) of the National Institute of Standards and Technology (NIST), is the latest in a series of independent peer reviews conducted annually by the National Research Council (NRC) since 1959.[1] Although commissioned by NIST as part of its process for continuous improvement, this assessment was conducted and written by a standing board of the NRC that is independent of NIST. This report is based on the observations and professional judgment of 144 independent, pro bono experts chosen by the NRC for their relevant technical expertise and appointed to the board on Assessment of NIST Programs and its seven panels. Most of these scientists and engineers visited NIST twice in 2003 for a total of 3 days of information gathering and to engage in extensive, in-depth discussions with NIST management and staff. Through this intensive process, the Board sampled enough programs to enable it to assess the technical quality of the MSL.

Part I of this report presents the overall assessment of the MSL, and Part II contains summary assessments of the component laboratories. Part III provides division-level reviews of the MSL, which include a wide range of observations and recommendations developed from the panels' extensive fact-finding activities. In this synopsis, the Board highlights key aspects of its assessment that should be of interest to the community of NIST stakeholders.

The Board is very impressed with the technical quality of NIST's intramural work. The reviewed programs range from very good to excellent, and some are clearly world-class. NIST programs are also highly relevant to its mission of enabling and advancing standards and technology for U.S. industry and commerce: most programs are clearly tied to that mission, and most MSL units have a good understanding of their customers and their needs. No other laboratory in the country has the same mission or capabilities to provide the range of services supplied by NIST.

In addition to its ongoing work in support of measurement and standards development, NIST provides great value to the nation as a resource offering scientific, engineering, and technical expertise

[1] Starting in 2004 the NIST laboratories will be assessed biennially. The next report will be published in September 2005.

that is readily available to address emerging, and sometimes unanticipated, challenges. A case in point is the work related to homeland security. Existing capabilities of the MSL enabled each of its laboratories to respond quickly to important homeland security needs. For example:

- The Electronics and Electrical Engineering Laboratory is developing technologies for non-invasive, in situ detection of weapons, lethal gases, and explosives.
- The Manufacturing Engineering Laboratory has contributed to increasing the cybersecurity of industrial control systems by helping to define and apply a common set of information security requirements for such systems.
- The Chemical Science and Technology Laboratory has created tools for identifying individuals on the basis of fragments of DNA.
- The Physics Laboratory is improving methods for sanitizing mail and inspecting cargo with high-energy X-rays.
- The Materials Science and Engineering Laboratory is investigating fundamentals of materials failure mechanisms associated with the collapse of the World Trade Center's Twin Towers to learn how the tensile and creep behavior of steel reacts to the extreme conditions produced by such a massive assault.
- The Building and Fire Research Laboratory has launched a major study to discover lessons to be learned from the Twin Towers' fire and collapse at the World Trade Center, and it is continuing relevant work to understand how fires spread within buildings and how contaminants disperse through ventilation systems.
- The Information Technology Laboratory is studying how to improve communications among first-responder emergency teams that rely on various types of equipment, and it is also building on its earlier work on biometrics for security systems.

There are many more opportunities for measurement and standards work to contribute in important ways to homeland security, and the Board believes that NIST has the capability of making significant additional contributions to this area.

The Board is pleased to see the degree to which NIST now disseminates information in digital format via the World Wide Web. Not only does this availability of information on the Web improve ease of use, but it also allows for the incorporation of additional useful tools, such as computational and graphical support. Clearly, providing digitized information is a key mechanism by which the MSL can maximize its value to the nation. The Board encourages NIST to improve to the greatest possible extent the efficiency with which it provides such information (so as to reduce the amount of effort that is taken from creating the information), while also maintaining traditional NIST quality.

The Board's response to recent developments with respect to NIST facilities themselves is mixed. The Board is relieved to hear that some funding has been slated to improve the Boulder, Colorado, campus, a move that is long overdue. Some of the basic infrastructure on that campus is in a precarious condition, which is especially worrisome given that some of NIST's most sophisticated work is performed there. The Board is also pleased that the Advanced Measurement Laboratory (AML) on the Gaithersburg, Maryland, campus—a state-of-the-art facility—will be finished this year. However, the small amount of funding allocated by Congress for the AML's start-up and operations raises concerns.

Overall, the Board continues to be impressed with the capabilities and accomplishments of the NIST Measurement and Standards Laboratories, and it looks forward to reviewing NIST's progress in the future.

1

The State of the Laboratories

The Board on Assessment of NIST Programs continues to be impressed by the vital and unique function served by the National Institute of Standards and Technology (NIST) Measurement and Standards Laboratories (MSL) in the development and transition of new technologies supporting national interests and also by the level of quality with which they carry out this work. The laboratories establish and maintain highly accurate, dependable measurement standards that are fundamental to sustaining commercial infrastructures and to the process of scientific discovery. No other laboratory in the country has the mission or capabilities to provide the range of services supplied by NIST.

In this first chapter, which constitutes Part I of the report, the Board presents its overall fiscal year (FY) 2003 assessment of the MSL, focusing on issues that affect the MSL as a whole. Chapters 2 through 8, which make up Part II, present analogous overview assessments for each of the component laboratories. The focus in those chapters is on observations, conclusions, recommendations, and discussions that should be of value to each laboratory's senior management. Part III consists of Chapters 9 through 15, which present detailed assessments of the technical programs within each of the laboratories. Part III is based on some 38 site visits during FY 2003 by most members of the National Research Council (NRC) panels involved in this assessment. The chapters in Part II represent the consensus views of the panels and Board and are based on the detailed observations contained in Part III.

Each project reviewed was evaluated in the context of overall NIST objectives. The Board estimates that a significant portion of the projects of the MSL were evaluated in the current cycle of site visits. The Board believes that this is a sufficiently robust sample of MSL projects to support a high-quality independent peer review.

QUALITY AND RELEVANCE

Technical Merit and Quality of Laboratory Programs

As has been the case consistently in recent years, the Board finds that the technical merit of the work performed in the NIST MSL generally ranges from very good to excellent. The Board bases this judgment on such factors as the level of technical skill and knowledge required by the problems addressed and the degree of excellence and creativity in the investigative approach. The Board believes that there is still some room for technical improvement, as there is in any research and development (R&D) organization, but the overall technical quality of the programs is not a concern.

The Board identified a number of technical programs that stand out as exemplars of NIST's best work:

- In the Electronics and Electrical Engineering Laboratory (EEEL), NIST scientists are applying Josephson junction technology and knowledge of the fundamental constants of nature to develop an "electronic kilogram," which will use the precision of voltage metrology to replace the standard mass samples on which we currently rely. This electronic kilogram will ultimately provide a unit of mass that is more uniform and replicable. Another example of EEEL's ongoing work in precision metrology is its use of the quantum Hall effect to measure the ohm. In the area of innovative technology, EEEL has developed a promising method for using high-frequency (terahertz) imaging as a way of looking through paper or clothing. An impetus for this R&D is to develop the capability of searching noninvasively for weapons, a homeland security application.
- The Manufacturing Engineering Laboratory (MEL) is delving generally into nanotechnology of importance to future manufacturing. For instance, MEL is pursuing an integrated dimensional and electrical metrology program that will lead to methods for the fabrication and characterization (dimensional and electrical) of nanoelectronic (below 50 nm in scale) quantum devices. In addition, MEL's ongoing work in the Microforce and the XCALIBIR (optical metrology) projects is now developing the impressive capability of measuring tens of nanonewtons (a nanonewton is a billionth of a newton).
- The Chemical Science and Technology Laboratory (CSTL) has pursued research in microfluidics that is now leading to dramatic improvements in concentrating and separating ions in microfluidic streams. These developments open the path to new capabilities in microfluidics control and analysis, which could be a key element of new biomedical techniques. Significant updates to CSTL's Mass Spectral Database are also noteworthy. This database—a long-standing technology that continues to provide a high-quality and reliable resource—is a "must-have" technology for many chemical laboratories.
- Some of the most striking accomplishments within the Physics Laboratory (PL) relate to its ongoing leadership in time and frequency technologies. For example, the extremely accurate time and frequency standards and measurements kept at NIST allow the calibration, synchronization, and interaction of various communications links. This capability is fundamental to the current revolution in the dissemination and use of information. The Board was impressed by the Web-based service of NIST that provides time and date stamps. This key service is used worldwide for a variety of Internet transactions and synchronizations; it is accessed a billion times a day, the highest hit rate for any NIST Web page. A promising and innovative new technology development is the recent creation of optical clocks that are based on self-referencing frequency combs. When coupled to NIST's emerging "atom on demand" technology, this advance could enable a leap ahead to the next generation of high-precision clocks.
- Among the many excellent programs of the Materials Science and Engineering Laboratory (MSEL), the advances in the lead-free solder program most impressed the Board. This program seeks to ameliorate a worldwide problem—the detrimental environmental effects of lead in discarded circuit boards manufactured with current lead-solder technology. If MSEL is successful in creating and transitioning lead-free soldering technology for the manufacture of circuit boards, it could provide the United States with a significant competitive advantage while reducing an environmental risk at the source and diminishing the need for downstream solutions.

• The Building and Fire Research Laboratory (BFRL) continues to improve its Fire Dynamics Simulator. This excellent scientific and engineering tool, which is based on scientific models and verified through field experimentation, is available and used worldwide. It promises to be a significant factor in the prevention and control of fires. BFRL responded to homeland security needs in the area of bioterrorism concerns by applying expertise within its Building Environment Division to develop a model for the spread of contaminants through buildings.

• One of the most impressive accomplishments this year by the Information Technology Laboratory (ITL) was the release of the updated *Handbook of Special Functions*, known to generations of users by the names of its original (NIST employee) authors, Abramowitz and Stegun. In addition to updating this classic, ITL will make it available online with computational and graphical support, making it even more useful and user-friendly than its predecessor was. Another important example of ITL work is its ongoing leadership in biometrics, which provides the foundation for a range of trustworthy security and surveillance systems, both current and emerging.

Program Relevance and Effectiveness

The Board applauds the relevance and effectiveness of the work of NIST's Measurement and Standards Laboratories. It evaluated relevance and effectiveness according to two overlapping dimensions: (1) how well the programs have met current needs and appear to anticipate and to act flexibly in meeting future needs of U.S. industry and commerce and (2) how well the programs are aligned with the current "customer" base. Overall, the Board finds the programs of the MSL to be well aligned with NIST's larger goals and mission in support of U.S. commerce.

The most striking evidence of NIST's flexibility in adapting to meet changing needs is its track record in quickly applying its base of expertise and experience to homeland security challenges that were unknown 2 years ago. This base of expertise and experience includes the following:

• Expertise in the analysis of DNA fragments, which became a crucial technology for identifying victims of the World Trade Center disaster;

• Capabilities for the evaluation of building structural weaknesses, which positioned NIST to undertake a major analysis of the causes of failure of the Twin Towers at the World Trade Center;

• Imaging technologies that could be readily adapted for noninvasive imaging of weapons;

• Communications expertise that enabled NIST to begin addressing how to overcome equipment mismatches that plagued first-responders at the World Trade Center site;

• Understanding of dosimetry of importance for treating mail that might carry bioterrorism agents; and

• Expertise in flow models for ventilation, which allowed NIST to quickly develop a plan for decontaminating the Hart Senate Office Building in Washington, D.C., after the anthrax attack of 2001.

Although the Board cannot predict which current projects are prescient about future needs, it was impressed by an ITL project that uses statistical methods for the analysis of variations in metrology among worldwide standards of importance to trade. While not glamorous, such an analysis could have very wide-ranging significance for U.S. industry in a globalized market. The lead-free solder program mentioned above is another example of an activity that demonstrates foresight.

Regarding the second dimension of relevance—how well programs align with the needs of the currently identified customer base—the Board notes the following positive practices:

- All of the major MSL units measure customer satisfaction.
- It is common to find MSL units communicating proactively with customers through customer surveys, workshops and technical meetings, and involvement in standards bodies.
- MSL units conduct economic impact analyses, where appropriate.

The number of "hits" on some NIST Web sites is an impressive indicator that NIST is reaching its customers. Another customer-oriented innovation is the development in some units of guides to good practice as a new service that complements the traditional standards.

The Board has one concern regarding relevance, which is that excellent customer relations can sometimes inhibit the pursuit of important new areas when an organization's overall resources are flat (as is the case with NIST). For instance, CSTL may have to phase out some of its analytical chemistry services in order to satisfy growing demands in the life sciences, and ITL may have to do less work of relevance to the FBI in order to serve other homeland security-related information technology needs.

RESOURCES

Facilities and Equipment

Some of NIST's laboratory facilities and equipment are excellent. CSTL, for example, is well equipped to carry out its demanding work; the only major area for improvement identified by the assessment panel for CSTL was a need to update the electronics in some existing microprobes. Within MEL, the Manufacturing Metrology Division retains world-class capabilities and has state-of-the-art facilities for a number of metrology services. The XCALIBIR and Microforce projects are excellent examples of newly developed, world-class capabilities derived from technical projects. The Physics Laboratory's Time and Frequency Division has two new laboratories that provide excellent environmental controls, other parts of PL are slated for partial equipment upgrades, and the laboratory facilities of some groups within EEEL have seen improvements. Additionally, there have been commendable safety upgrades at the Boulder campus.

The Board is pleased to hear that some funding has finally been slated to improve the Boulder buildings, a move that is long overdue. As noted in Chapters 9 and 12, serious problems exist that significantly threaten NIST's ability to conduct its work at Boulder, and the budget to correct these problems is not within NIST's control. For instance, the country's primary atomic clock is located in a building with a leaky roof, and some of EEEL's work is threatened by serious electromagnetic interference from nearby areas.

Some NIST units are experiencing space constraints that could ultimately inhibit their productivity and/or quality of work. For instance, EEEL still needs facility upgrades in Boulder, and some divisions are dispersed in different buildings, which limits their synergies. NIST's joint program with the University of Colorado, JILA (formerly the Joint Institute for Laboratory Astrophysics), still suffers from insufficient laboratory space. Plans for the construction of a biological wet-lab at JILA have not been completed; such a laboratory would facilitate the development of important new work. Overall, the quality of some space on the Boulder campus is not consistent with the quality of the work being done there. As another example, BFRL could be positioned to do high-quality, high-impact work in structural fire testing, an important element of homeland security and an appropriate long-term programmatic growth area for BFRL and its customers—but this work will require the construction of a state-of-the-art facility for the fire testing of structures under load, plus a commitment to sustain a structural fire research program over the long term.

NIST faces a significant challenge in moving into the Advanced Measurement Laboratory (AML) on the Gaithersburg, Maryland, campus because of budget shortfalls for moving and for facility operations once the move is completed. The AML represents the state of the art in a facility for physical sciences research and metrology, with impressive specifications for temperature, humidity, vibration control, and power. As such, it presents a tremendous opportunity for future efforts at NIST. But it is not sensible, or in fact sometimes even possible, to have current equipment simply moved into the facility's new buildings without significant interruptions of calibration services or substantial risk to precision equipment. These challenges add to the normal complexity of moving, and they will require staff to undertake additional planning in order to avoid degradation of performance during FY 2004.

Human Resources

The human resources at NIST remain very strong and constitute an extremely valuable resource for the nation. According to an internal survey conducted during 2002, employee morale is generally high; this conclusion comports with impressions gleaned by the Board's panels during their site visits in 2003. The working environment at NIST encourages a high rate of employee retention.

With respect to human resources, NIST should continue its attention to maintaining balance in the following areas:

- Between regular and temporary employees, to ensure the continuance of key organizational knowledge;
- Between service and research activities, to ensure faithfulness to NIST's standards mission while keeping NIST at the forefront of the research that will enable and support future standards activities (see the next section, "Balance of Service and Research");
- Between administrative support staff and technical staff, to maximize technical productivity; and
- Between professional staff and laboratory technicians, to allow the best and most cost-effective distribution of assignments.

In addition, NIST should ensure that technical employees have access to mentors and training in order to develop staff members for technical leadership positions. NIST also should develop plans that anticipate the need to replace key technical skills as employees retire or move to other opportunities.

BALANCE OF SERVICE AND RESEARCH

The overriding mission of NIST is service to the nation through the development and dissemination of advanced methods and standards that serve industry, commerce, and other national needs. However, staying at the frontier (or pushing the frontier) of measurement science requires a sophisticated and aggressive research program. The balance between research and services within NIST's MSL is generally good.

The challenge of striking and maintaining the best balance can be illustrated by the program of the Manufacturing Engineering Laboratory. Preparing for the next generation of manufacturing technology requires attention to intellectual challenges that call for deep thought and long gestation periods. At the same time, the U.S. manufacturing community is confronted by practical issues that require quick, workable solutions that are rapidly available. Facing such varied demands is exemplified in the work of MEL's Manufacturing Systems Integration Division (MISD). That division's main objective is to help manage the ever-increasing complexity of the manufacturing environment, in which every year new systems make old ones obsolete, and technology performs new functions that may not previously have been considered part of the manufacturing enterprise. New technologies might stem from and/or incorporate new computer languages, software, operating systems, hardware and software platforms, communications protocols, and so on. Overlying such technical factors are broader considerations: competition is fierce and cost-consciousness is becoming more prevalent.

To help manage these complexities, MSID is heavily engaged in work on interoperability issues—the issues related to how these various parts of the manufacturing enterprise work together, and how interoperation can be automated, since the complexity of the systems has moved beyond the capabilities of manual controls. Because the rapidity of change is also increasing, manufacturing engineers rely on MSID, which fills a niche in the manufacturing environment not addressed by programs at universities or other federal laboratories, or by vendors. The complexity of the issues calls for time lines and a depth of understanding akin to what would otherwise be addressed in academic research. However, the ultimate industrialization of new technologies must also be considered; they must be timely, reliable, and suitable for real-world use.

A different aspect of service is seen when one NIST unit provides expertise to support the work of another—for example, when ITL expertise contributes to the goals of MSID. Such internal consulting is one of the roles of ITL. Its knowledge base in information technology (IT) is an important resource for most other NIST laboratories, because most rely on advanced IT in some way for their instrumentation and technologies or for the dissemination of their results. Two of ITL's divisions consult internally and provide in-house training; other NIST divisions also provide occasional in-house training courses. NIST must ensure that such supporting activities are appropriately recognized and valued as true collaborations.

Recent homeland security work at NIST illustrates another consideration in gauging the right balance between service and research: that is, the research directions at NIST today are what will position it to provide services to address future needs. Expertise developed over years of work created a foundation in DNA analysis, radiation dosimetry, structural analysis, fire research, communications technologies, and other areas that could be quickly retargeted to address particular questions of importance to homeland security. By maintaining a broad research base, sometimes in areas that are neglected by other research institutions, NIST has the capability of responding rapidly to unforeseen national needs as they occur.

HOMELAND SECURITY ACTIVITIES

As a special focus in 2003, the Board investigated how NIST's intramural programs were being affected by the new emphasis on homeland security work. Overall, NIST has responded very well, and the redirection or expansion of some efforts into important homeland security work has been very positive. The demands of homeland security have illustrated the value to the nation of NIST's broad range of expertise. Existing capabilities have enabled every in-house laboratory at NIST to respond quickly and authoritatively to important homeland security needs. For example:

- The Electronics and Electrical Engineering Laboratory is developing technologies for noninvasive, in situ detection of weapons, lethal gases, and explosives.
- The Manufacturing Engineering Laboratory has contributed to increasing the cybersecurity of industrial control systems.
- The Chemical Science and Technology Laboratory has created tools for identifying individuals

on the basis of fragments of DNA.

- The Physics Laboratory is improving methods for sanitizing mail and inspecting cargo with high-energy X rays.
- The Materials Science and Engineering Laboratory is investigating fundamentals of materials failure mechanisms associated with the collapse of the World Trade Center's Twin Towers.
- The Building and Fire Research Laboratory has undertaken a major study to discover lessons to be learned from the Twin Towers' fires and collapse at the World Trade Center, and it is continuing relevant work to understand how fires spread within buildings and how contaminants disperse through ventilation systems.
- The Information Technology Laboratory is studying how to improve communications among first-responder emergency teams that rely on various types of equipment, and it is also building on its earlier work on biometrics for security systems.

There are many more opportunities for measurement and standards work to contribute in important ways to homeland security, and the Board encourages NIST to undertake more work related to this area, especially when it leverages and complements other important NIST activities. It recommends that NIST continue to focus, define, and coordinate NIST expertise in relevant areas and demonstrate NIST capabilities to the entire homeland security community.

OTHER ISSUES

The flat budgets that NIST has experienced in recent years are a fact of life for now, and they will necessitate difficult choices in the pursuit of technical advancement. In order to maintain overall technical quality and productivity, NIST managers should continue to increase emphasis on systematic planning and priority setting—with the understanding that some popular and successful programs at the bottom of the priority list will have to be eliminated, so that those with higher priorities can prosper. The Board has noted some resistance to systematic planning; for instance, Chapter 5 notes that the Physics Laboratory has made little response to the calls in the Board's 2001 and 2002 reports for that laboratory to develop more useful planning guidance for decision making in technical programs. Most parts of the MSL have been stretched thin in recent years because of very lean budgets. Unless that trend is reversed or the MSL make strategic decisions to eliminate low-priority programs, the quality of the work will begin to suffer.

Even in a time of flat budgets, the NIST Strategic Focus Areas (SFAs) and similar initiatives yet to be defined do offer opportunities for growth. NIST has had good success in moving into homeland security work, as noted above, and staff could be even more aggressive about bringing their capabilities to communities targeted by the SFAs.

There is still work to be done to break down barriers to collaboration within NIST in order to make it easier to apply the best mix of expertise to technical problems. The Board saw many good examples of cross-laboratory collaborations at the bench level and concludes that the research staff is not constrained by organizational barriers. However, the Board saw little evidence of collaboration at higher levels—for example, joint programs or collaborative planning.

Because the Board's charge calls for it to assess the relevance and effectiveness of NIST's technical intramural work and because relevance and effectiveness must be measured against NIST's mission and goals, the Board relies on receiving a clear picture of the organization's high-level objectives. The Board is gratified to see good progress across MSL units in specifying missions and goals. The overall

NIST strategic plan (the NIST 2010 plan[1]) gives useful guidance. In addition, the Strategic Focus Areas have been very effective at clarifying major directions and coordinating efforts in the NIST program. These strategic plans are now influencing programmatic decisions in a healthy way, and there seems to be a broad understanding throughout NIST of what is in the overall plan.

Within some laboratories the Board sees useful operating plans that are based on the strategic plan; in other laboratories the operating plans are still emerging. The Board believes that insightful, internally generated operating plans are essential for making optimal technical management choices, especially during periods of flat budgets such as the present.

The effectiveness and value of some NIST programs have increased greatly in recent years owing to the availability of results in digital form. The use of a Web site for providing time stamps, noted above, is a natural and invaluable extension of NIST's traditional dissemination of the official time by radio. Making compilations of information—for example, the updated *Handbook of Special Functions*, the *Guide to Available Mathematical Software*, and the Mass Spectral Database—available in digital form not only improves the ease of use of such compilations but also allows for the incorporation of additional useful tools, such as computational and graphical support. Clearly, providing digitized information is a key way for the Measurement and Standards Laboratories to maximize their value to the nation.

The amount of digitized information disseminated by NIST now necessitates general policies to ensure the efficient use of resources (human and other) and to maintain the traditional quality associated with NIST products and services. In 2004, the Board will examine how NIST is addressing this challenge.

[1]U.S. Department of Commerce, National Institute of Standards and Technology, *Preeminent Performance—The NIST 2010 Strategic Plan*, National Institute of Standards and Technology, Gaithersburg, Md., August 2002. Draft for public review and comment available online at <HtmlResAnchor http://www.nist.gov/director/planning/nist2010_plan.pdf>.

PART II
Summary Assessments of the Individual Laboratories

Part I of this report presents the Board's synopsis of the 2003 assessment and its overall assessment of the NIST Measurement and Standards Laboratories. This part provides a laboratory-level assessment of each individual laboratory. Part III presents a technical review at the division level for each laboratory.

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Electronics and Electrical Engineering Laboratory

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Submitted for the panel by its Chair, Constance J. Chang-Hasnain, and its Vice Chair, Robert R. Doering, this assessment of the fiscal year 2003 activities of the Electronics and Electrical Engineering Laboratory is based on site visits by individual panel members, a formal meeting of the panel on February 20-21, 2003, in Gaithersburg, Maryland, and documents provided by the laboratory.[1]

[1]National Institute of Standards and Technology, Electronics and Electrical Engineering Laboratory, *Programs, Activities, and Accomplishments, NISTIR 6625, 6626, 6627, 6628, 6933, 6934, 6952, 6953*, National Institute of Standards and Technology, Gaithersburg, Md., January 2003. These books for the EEEL divisions are available online at <http://www.eeel.nist.gov/lab_office/documents.html>.

LABORATORY-LEVEL REVIEW

The mission of the NIST Electronics and Electrical Engineering Laboratory (EEEL) is to strengthen the U.S. economy and improve the quality of life by providing measurement science and technology and by advancing standards, primarily for the electronics and electrical industries. This statement is supported by a strategic plan, which was revised during 2002.[2]

EEEL is organized in six divisions and two offices: the Electricity Division, Semiconductor Electronics Division, Electromagnetic Technology Division, Radio-Frequency Technology Division, Optoelectronics Division, Magnetic Technology Division, Office of Microelectronics Programs (OMP), and Office of Law Enforcement Standards (OLES) (see Figure 2.1). This chapter provides an assessment of the laboratory overall, and each division is reviewed in Chapter 9. The discussion of OMP is included in the section "Semiconductor Electronics Division" in Chapter 9. The OLES was not reviewed during fiscal year 2003.

Major Observations

The panel presents the following major observations from its assessment of the Electronics and Electrical Engineering Laboratory:

- The work in EEEL continues to be of very high technical merit and quality. Many staff members are recognized as world leaders in their fields. In general, there is significant linkage between EEEL projects and the goals of the laboratory supporting NIST's mission. This situation is due largely to the efforts of an intensely committed staff and to management's support and recognition of the value of these efforts. So that EEEL can achieve greater impact through higher visibility, the panel recommends a more concerted effort to publicize the accomplishments of EEEL research and its satisfactory customer services.
- In general, the morale of the staff in the laboratory remains high. This is due principally to the excellent work environment, talented and helpful co-workers, and significant flexibility in conducting research.
- The extended period of excessively lean budgets for the support of current laboratory activities now clearly has an influence on its present and future capabilities and effectiveness. Short budgets present significant constraints on the laboratory's capabilities to execute its strategic plan and, in particular, seriously affect succession planning because it is not possible to hire new people until experienced staff members have retired. To prevent the loss of valuable knowledge, new people should be hired and trained by experienced staff members prior to their retirement. In addition, the panel is very concerned with the reduction in numbers of personnel resulting from the continued static or declining budgets and also with the ultimate impact of these reductions on staff morale and the technical quality of work.
- Planning for the equipping and use of the Advanced Measurement Laboratory (AML) is now in progress; however, the panel is highly concerned with the fact that insufficient funding is available to move personnel and sophisticated equipment into the facility and to support the AML's operations once

[2] U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Electronics and Electrical Engineering Laboratory Strategic Plan 2002*, NISTIR 6844, National Institute of Standards and Technology, Gaithersburg, Md., February 2002.

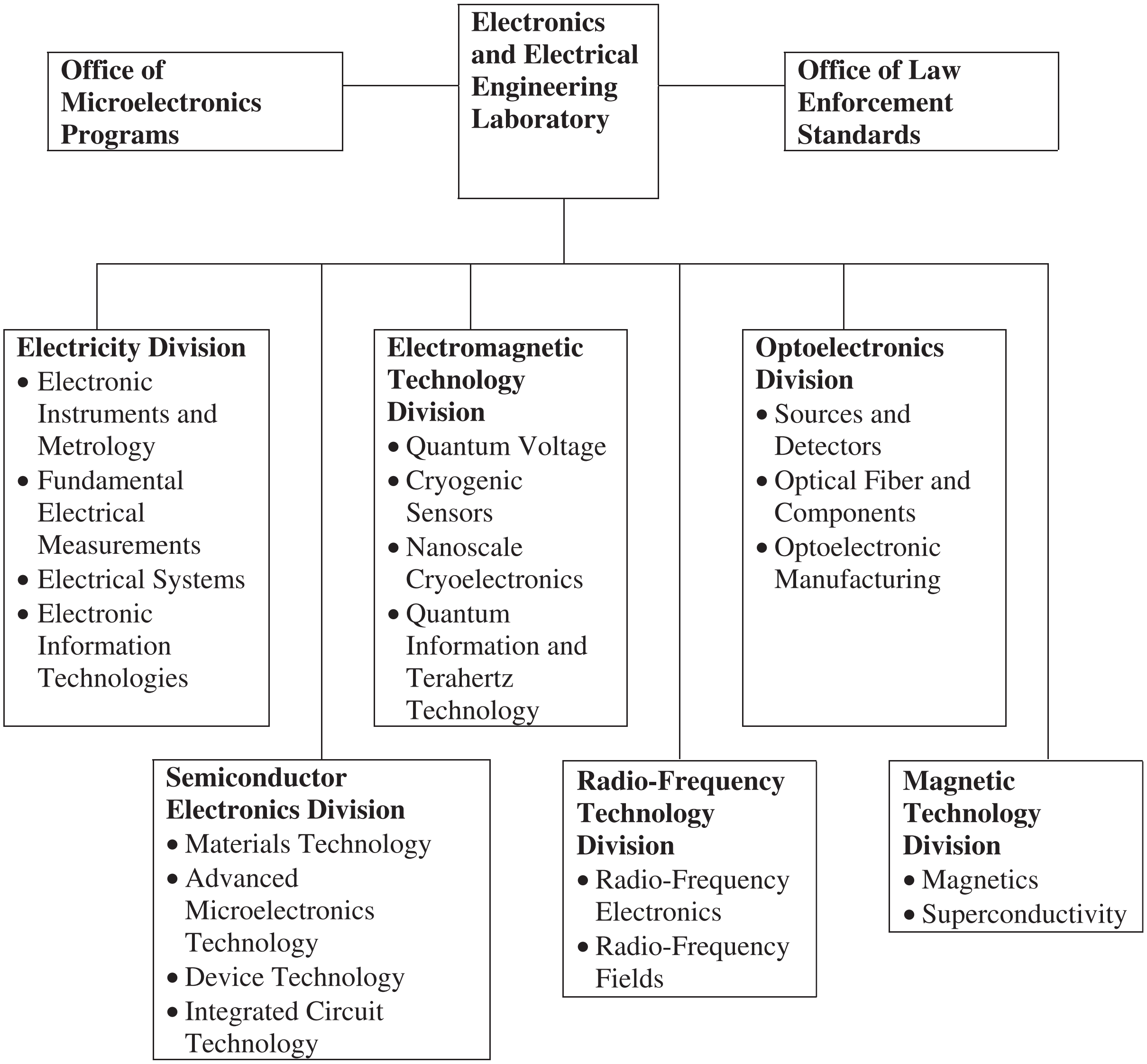

FIGURE 2.1 Organizational structure of the Electronics and Electrical Engineering Laboratory. Listed under each division are its groups.

it is occupied. Prolonged moving periods will disrupt normal laboratory activities and the capacity at which the AML's services can be provided. At the present time there is no assurance that adequate funding will be made available to support the move, start-up expenditures, and operational and maintenance costs.

• The panel supports EEEL's efforts in staff preparation for leadership positions and encourages continued and augmented training opportunities to deal with issues of succession associated with the impending retirement of key managerial personnel. In addition, the panel recommends more communication between management and staff on the alignment of rewards with performance indicators.

• Impressive progress has been made by the staff in realigning projects with the Strategic Focus Areas and toward OA opportunities. The panel recommends a more focused and coordinated effort across divisions to effectively leverage expertise and capabilities.

Technical Merit

The technical merit and quality of research and services carried out by EEEL continued at a very high level during this assessment period. Many projects navigate the cutting edge of scientific understanding and are closely integrated with and serve to advance the standards and calibration services that the laboratory is asked to perform. In the following brief list the panel points out some of the projects that stand out for their excellence and that illustrate the merit of the laboratory's work:

• EEEL programs in metrology continue to be at the forefront of similar efforts, with many measurements achieving the world's best performance—including the volt, the ohm, optical power, and wavelength standards, among others. These programs help to retain U.S. leadership in the field of standards, and in some cases eventually redefine the standards. The panel was particularly impressed with the exceptional level of technical skill and creativity of the laboratory's researchers.

• The Electronic Kilogram project continues to advance, with the goal of providing an alternative definition of the unit of mass that is based on measured quantities determined by fundamental physical constants of nature. The unit of mass is currently based on a physical artifact, whose copies differ by non-negligible amounts. The project combines the use of a number of existing electrical standards (the volt and the ohm) in order to generate a known force through means of a complex, yet fundamentally deterministic, magnetic system. Numerous foreign bureaus of standards are making efforts to eliminate these artifacts. The program at NIST is at the forefront of these efforts.

• The Advanced MOS (metal-oxide semiconductor) Device Reliability and Characterization project has successfully kept pace with mainstream International Technology Roadmap for Semiconductors (ITRS) requirements for silicon dioxide measurements. Research efforts continue to provide fundamental understanding and physical models for the investigation of silicon dioxide failure mechanisms. The NIST standards are now being adopted internationally and are being used, for example, in the qualification of offshore foundries.

• The Quantum Information and Terahertz Technology project involves the development of sensors with improved accuracy, speed, and sensitivity in the millimeter-wave and near-infrared regime. Applications include the identification of concealed weapons at room temperature, astrophysical applications, and use as a diagnostic tool in semiconductor processing. The impact of this project is significant, particularly with respect to providing excellent support for national interests in homeland security, communications, and computing.

• The Nonlinear Device Characterization project characterized the phase error in the nose-to-nose calibration of sampling down converters. This advance has uncovered a previously ignored, fundamental calibration issue that causes a large uncertainty error. Also, a more general, nonlinear definition of scattering parameters was developed in collaboration with a University of Colorado faculty researcher; it uses a matrix formulation and reduces to the classical definition for linear networks.

• The Metrology for Bioeffects of RF (Radio-Frequency) Energy project in support of the National Institutes of Health is conducting research using reverberation chamber technology. Rats are modeled by 0.5-liter water bottles, and the effect of multiple such phantoms on field distribution in reverberation chambers is being investigated. This work should result in a more efficient and repeatable method of evaluating potential health effects of low-level RF fields than that provided by currently available techniques.

- Ultrahigh-speed photo detector measurements have been extended from 65 GHz to 110 GHz. Further, the vector response—a capability providing both the magnitude and phase of the frequency response of high-speed detectors—has been added. This important activity potentially addresses many major new applications areas, such as wireless communications, microwave photonics, and test equipment development and calibration.
- The Single Molecule Manipulation and Measurement initiative has made substantial progress with the construction and testing of a micromachined magnetic trap fluid cell. The ability to sort and store molecules should have wide-ranging applications in chemical and biological industries.
- The chip-scale atomic clock utilizes a microelectromechanical system (MEMS) Cs vapor cell for miniaturizing an atomic clock while keeping precise time measurements. This clock should be very useful for homeland and military security and for wider industrial applications in which small, relatively inexpensive devices to provide time standards are needed.

Program Relevance and Effectiveness

EEEL serves a wide array of customers, primarily in the electronics and electrical industries (including utilities, telecommunications, and wireless industries), and microelectronics and optoelectronics manufacturers. Laboratory efforts that support this work are included in the custody, maintenance, and optimization of highly accurate standards for electrical units; precise calibrations of electrical quantities; and the development of measurement infrastructures for semiconductor, superconductor, optical networking, magnetic storage, and wireless-based services.

The panel believes that EEEL divisions are doing an excellent job of providing services, interacting with their customers, performing scientific research, and circulating the results of their investigations. For example, EEEL researchers are world-recognized experts in the area of optoelectronics and have a reputation for supplying the world's best calibration services. Interest in their work is demonstrated by the high level of invited talks and journal articles that they produce each year. EEEL staff members continue to participate in standards bodies and literally set the standard for quality in the optoelectronics industry. Measurement techniques and calibration services in this area have recently been expanded to support technologies under development for homeland defense.

Work in the Magnetic Technology Division features close collaboration between industrial and government partners for the development and support of technologies of current national interest: for example, high-speed nanoscale recording systems for the forensic analysis of tapes, magnetic field mapping, and molecular manipulation as part of the Single Molecule Manipulation and Measurement initiative. Discoveries from this division are providing solid underpinning for the next generation of magnetic data storage and microelectronics industries.

Standards development, test methods, and services of the Radio-Frequency Technology Division are supporting the radio-frequency technologies and electromagnetic compatibility needs of U.S. industry. This division is actively involved in international and domestic standards activities to provide physically correct test methods and calibration service for U.S. trade and to serve as an impartial expert body for resolving potential worldwide measurement inconsistencies.

Industry views the Semiconductor Electronics Division's contributions as unique and essential to efficiently providing measurement techniques and standards. NIST's being in a position to provide methods and standards without bias is seen as extremely beneficial to the overall industry and is unequaled by any other organization. No other body can provide this unique combination of skills and capabilities.

The Electromagnetic Technology Division's development of quantum standards serves the electronics industry with its voltage and capacitance standards as well as its sensors for X-ray analysis. Novel X-ray and infrared sensors have been used in radio astronomy. The development of quantum and nanoscale technology also provides the technological base for future sensors and standards. Terahertz sensors have been used in a prototype of a concealed weapons detection system, and superconducting circuits have been demonstrated for quantum computing that can be useful for revolutionary improvements in computing, communications, and encryption.

Programs in EEEL clearly serve a broad range of scientific and commercial pursuits currently of interest to the nation. In the FY 2002 report, the panel cautioned about the necessity to avoid supporting programs that are no longer useful and suggested applying built-in checkpoints as a method to monitor current and future interest in a project. This panel still does not see that formal checkpoints are being built in to projects. These checkpoints would be specific times in the project plans at which input from customers on the project's goals, objectives, and progress would be sought. These interactions would provide an opportunity to validate the appropriateness of continuing programs and would allow for midcourse corrections that take into account shifts in customer priorities or focus.

Laboratory Resources

Funding sources for the Electronics and Electrical Engineering Laboratory are shown in Table 2.1. In January 2003, staffing for EEEL included 242 full-time permanent positions, of which 202 were for

TABLE 2.1 Sources of Funding for the Electronics and Electrical Engineering Laboratory (in millions of dollars), FY 2000 to FY 2003

Source of Funding	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (actual)	Fiscal Year 2003 (July 2003 estimate)
NIST-STRS, excluding Competence	32.5	34.8	36.3	45.8
Competence	2.1	2.0	2.0	2.3
ATP	1.4	2.1	3.4	3.0
Measurement Services (SRM production)	0.2	0.3	0.3	0.2
OA/NFG/CRADA	13.8	19.7	20.9	30.0
Other Reimbursable	2.8	3.2	3.2	3.2
Total	52.7	62.0	66.1	84.5
Full-time permanent staff (total)[a]	259	244	242	242

NOTE: Funding for the NIST Measurement and Standards Laboratories comes from a variety of sources. The laboratories receive appropriations from Congress, known as Scientific and Technical Research and Services (STRS) funding. Competence funding also comes from NIST's congressional appropriations but is allocated by the NIST director's office in multiyear grants for projects that advance NIST's capabilities in new and emerging areas of measurement science. Advanced Technology Program (ATP) funding reflects support from NIST's ATP for work done at the NIST laboratories in collaboration with or in support of ATP projects. Funding to support production of Standard Reference Materials (SRMs) is tied to the use of such products and is classified as "Measurement Services." NIST laboratories also receive funding through grants or contracts from other [government] agencies (OA), from nonfederal government (NFG) agencies, and from industry in the form of cooperative research and development agreements (CRADAs). All other laboratory funding, including that for Calibration Services, is grouped under "Other Reimbursable."

[a]The number of full-time permanent staff is as of January of that fiscal year.

technical professionals. There were also 39 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Overall, the panel believes that the laboratory is doing the best it can to support its mission, given the constraints of personnel and fiscal resources as well as aging equipment and facilities. In EEEL, the budget gap is mended mostly through the painstaking and creative efforts of the staff to fill in personnel gaps with postdoctoral associates, students, and part-time staff; to increase the levels of outside other agencies (OA) and Advanced Technology Program (ATP) funding; and to use creative approaches to build outside collaborations that result in the expansion of experimental resources. As an example, the Semiconductor Electronics Division is partnering with SEMATECH to use its critical dimension (CD) measurement capability to support metrology needed by the semiconductor industry. Additionally, members of the research staff have volunteered their time to upgrade and recycle existing equipment to meet the requirements of advanced experimentation.

Across the board, laboratory projects continue to struggle with non-inflation-adjusted budgets and loss of personnel. These constraints inevitably restrict the ability to be responsive and, to a lesser extent, innovative vis-à-vis the changing reality of metrology in an international context. The panel observes that shrinking budgets create an ever-shrinking workforce. As more and more is asked from each division operating under the constraint of maintaining legacy systems, salary increases with decreasing budgets force the division not to replace personnel as they retire or leave. Additionally, senior staff turnover due to retirement is expected to be high over the next 3 to 5 years, meaning that there will be a loss of valuable expertise. Succession planning factored with strategic planning is critical to the future health and survivability of the divisions. Such planning must be done before the staff shrinks further, so that critical work can be continued while new capabilities are developed.

Examples of the impact of limited resources on the division's effectiveness are available. The Time Domain Measurements Group, for one, has turned down homeland security projects because of the lack of needed human resources. The primary researcher on the Gaithersburg single-electron transistor (SET) project is forced to spend months of his time dealing with commercial equipment failures. Unavoidable demands of calibration services hamper the essential development of modern AC-DC transfer devices. Each of these examples involves intensely committed staff members whose value is clearly recognized by division and laboratory management and who are actively supported, based on sound judgment, to the extent of current funding capabilities. But limitations on those funding capabilities are now having a direct and negative impact. It must be made clear that this situation will likely not, in the panel's opinion, be addressed by additional reallocation of resources, as has already happened for some projects; because overall resource allocation is so thinly stretched, equally troublesome examples would quickly turn up in other programs. The problem is instead related to the overall level of support.

A serious concern linked to funding is the occupancy and use of the new AML facility. The AML buildings represent the state of the art in physical sciences research and metrology, with impressive specifications for temperature, humidity, vibration control, and power; these buildings present a tremendous opportunity for future efforts at NIST. The panel is pleased that detailed plans are in place and that ongoing planning adjustments are being made, with operational units strongly involved, to accomplish the move into the AML facility should funds become available. However, funding appears to be inadequate for properly and effectively moving into and using this world-class facility. Although the panel learned that efforts are being made to secure the funds needed, there is no assurance that they will be provided. It would not appear to be sensible, or in fact sometimes even possible, to have current equipment simply moved into the new buildings without significant interruptions of calibration services or substantial risk to precious equipment. A realistic evaluation of the funding required to capitalize on the nation's prudent investment in these new buildings should be made. There is significant concern that the facility's clean room, once operational, may be underutilized owing to insufficient capital equipment. Finally, the panel is very concerned that the equipment operation and maintenance costs may not be fully budgeted. The panel strongly recommends developing a plan that is comprehensive and that aligns well with NIST's long-term strategic plan.

The lack of provisions for steady equipment infrastructure improvements is a perennial worry to EEEL management, which realizes that the laboratory cannot remain at the cutting edge without constant and systematic upgrading of the experimental facilities.

The panel again deems the current status of Building 24 on the Boulder campus to be marginally functional. Although the condition of the facility has improved, its current state will significantly compromise NIST's ability to perform near-field antenna pattern measurements as they continue to push to higher frequencies (beyond 110 GHz); a prime example is the new Millimeter Planar Near Field system. Continuing the development of facilities for higher frequencies will enhance the laboratory's understanding of the limitations imposed by the current facility. In addition, the panel repeats its recommendation from last year's report to significantly upgrade the Boulder facilities.

The Radio-Frequency Technology Division has envisioned—and has developed a proposal for—a new, world-class radio-frequency electromagnetics experimental research and measurement standards facility that responds to the status of electromagnetic (EM) field technology users and will enhance the ability of NIST to carry out its mission to support industry. The panel believes that this new facility is critical to the future success of the division and recommends that the effort be pushed forward. The short-term plans for enhancing the existing laboratories will result in more resistance to developing the RF-EM Field Metrology Laboratory: "There is nothing more permanent than a temporary situation."

Laboratory Responsiveness

The laboratory's responses to most of the concerns presented in the FY 2002 report, as well as the speed and level at which these changes have taken place, are generally impressive.

First of all, the panel applauds the effort in the development of the EEEL Operational Plan and the beginning of an effort to align EEEL projects with NIST Strategic Focus Areas. The panel recommends the continuation and refinement of the Operational Plan so that it becomes broadly adopted within the laboratory, as well as continuous communication with all staff members to ensure a higher level of understanding.

One panel recommendation in last year's report related to the development of project evaluation criteria—key milestones with quantitative benchmarks. The panel saw significant efforts and progress being made in this direction. The panel believes that this is one of the most important aspects in project management and recommends the continuation of focused effort in this regard.

The panel notes significant progress in the establishment of a systematic approach for the use and equipping of the AML. In particular, major progress has been made this past year in the development of an overall clean room utilization plan and associated capital equipment list. The plan, which has been agreed to by all of the NIST laboratories, is a major accomplishment. However, as discussed in the previous section, the panel is still concerned about the inadequacy of funding for the acquisition of essential and state-of-the-art equipment; the move of equipment and people into AML; the setup, operation, and maintenance of the equipment; and the upkeep and maintenance of existing activities during the move.

Examples of the laboratory's commendable responsiveness to the FY 2002 report include the reorganization and redirection of projects in the Electricity Division to improve resource allocation and productivity. The Electromagnetic Technology Division increased its staff size and added a new dilution refrigerator to overcome measurement bottlenecks. In the Radio-Frequency Technology Division, significant progress has been made in the automation of calibration processes—an effort is to be commended.

The Optoelectronics Division has increased calibration services for higher-power, fiber-coupled power meters, extended high-speed photodetector calibration services to 110 GHz, and increased research in the area of polarization mode dispersion measurement and emulation. The researchers from the division greatly increased their visibility by leading industry workshops in this important field of study and setting up a Web site for wider dissemination of results.

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Manufacturing Engineering Laboratory

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Submitted for the panel by its Chair, Marvin F. DeVries, and its Vice Chair, Richard A. Curless, this assessment of the fiscal year 2003 activities of the Manufacturing Engineering Laboratory is based on site visits by individual panel members, a formal meeting of the panel on March 25-26, 2003, in Gaithersburg, Maryland, and the documents provided by the laboratory.[1]

[1]Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Programs of the Manufacturing Engineering Laboratory 2003*, National Institute of Standards and Technology, Gaithersburg, Md., 2002.

LABORATORY-LEVEL REVIEW

The mission of the Manufacturing Engineering Laboratory (MEL) is to satisfy the measurements and standards needs of U.S. manufacturers in mechanical and dimensional metrology and in advanced manufacturing technology by conducting research and development, providing services, and participating in standards activities. The Manufacturing Engineering Laboratory is organized in five divisions: the Precision Engineering Division (PED), Manufacturing Metrology Division (MMD), Intelligent Systems Division (ISD), Manufacturing Systems Integration Division (MSID), and Fabrication Technology Division (FTD) (see Figure 3.1). The first four divisions are reviewed in this report. This chapter provides an assessment of the laboratory overall, and division-level reviews are presented in Chapter 10.

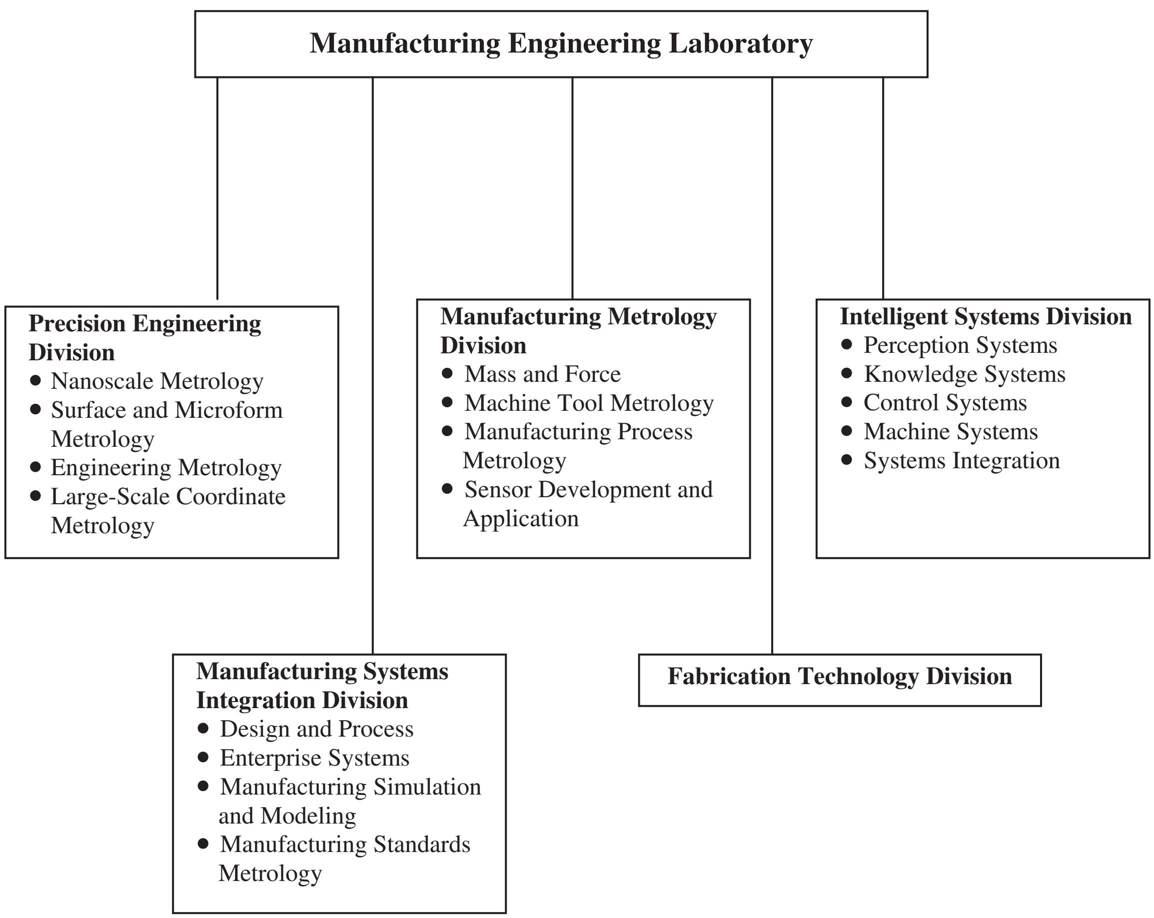

FIGURE 3.1 Organizational structure of the Manufacturing Engineering Laboratory. Listed under each division are its groups.

Major Observations

The panel presents the following major observations from its assessment of the Manufacturing Engineering Laboratory:

- All divisions were found to be doing excellent technical work in general. For the programs evaluated, the divisions in many cases were able to demonstrate that their activities were focused on the programs determined essential and most important to their mission. In certain cases, projects need reevaluation and redirection on the basis of work done elsewhere, and some shifts in priorities need to take place.
- Many projects represent world-class initiatives. Exemplary projects include the microforce realization and the XCALIBIR (X-ray Optics Calibration Interferometer) projects (in MMD); the Intelligent Control of Mobility Systems project (in ISD); contributions to the STEP (Standard for the Exchange of Product model data) initiative (in MSID); and the scanned probe oxidation lithographic technique, application of the Monte Carlo technique to metrology for precision engineering, and the advanced capabilities of the M48 coordinate measurement machine (CMM) (in PED). PED's efforts in establishing reference standards for bullet and casing markings are also significant achievements relevant to an important social need.
- A formal process and format should be established for planning and reporting project time lines and displaying a clear roadmap of current and planned activities, with a focus on continual process improvement.
- The panel's discussions with MEL management and technical staff suggest that the matrix management process is beginning to work (e.g., it is facilitating 14 MEL cross-divisional projects) and that the organization is becoming comfortable with it (e.g., project leaders are having more input into the performance appraisals of the staff they oversee).
- Systematic collaboration among the divisions is showing progress. An overview of crosscutting programs should be presented for the panel at the division reviews to show how these programs relate to the division's activities and how effectively the divisions are performing within these programs. The success of division collaboration can be expanded to embrace other NIST laboratories.
- MEL is working effectively to broaden its customer base and is establishing processes to identify best initiatives to help customers. Management has initiated workshops and forums, made trips to key customers, and provided communications among government, industry, academia, and associations. Projects need to consider a life-cycle plan that addresses bringing a project to a conclusion and includes a deployment plan to deliver the project results effectively to the target customers.
- Best practices and evaluations of the state of the art are needed that consider work accomplished and are then used to determine what and how new projects are to be developed. Data gathered from workshops, forums, published works, and standards committees can be used to prepare gap analyses that can be used to help determine needs and priorities.

Technical Quality and Merit

The quality of research in the Manufacturing Engineering Laboratory is high overall; in general, all divisions are doing excellent technical work. In some areas, MEL work is state of the art relative to work being performed worldwide. The laboratory appropriately emphasizes collaborative work. In general, the staff remains competent and motivated to fulfill roles of technical leadership.

Following are examples of projects demonstrating a high level of technical quality and merit:

- *Within the Precision Engineering Division:*

—Significant advances in fundamental understanding in the areas of scanning electron microscopy (SEM) and optical microscopy continued in 2002. This work is central to the efforts of the division and is of value to industry in both critical dimension and overlay metrology. Closely interacting with the industry consortium International SEMATECH (ISMT), the division has provided critical guidance to metrology efforts in the semiconductor industry. The model-based line width metrology is finding acceptance among SEM manufacturers, and the overlay research and tool development are central to overlay benchmarking and calibration.

—The staff of the Surface and Microform Metrology Group are highly regarded in the technical community; their work is world-leading despite the fact that in some cases NIST instrumentation is lagging behind that currently available in industrially based laboratories. The group is very involved in national and international standardization for surface metrology and has made significant contributions to these standards—for example, the ASME-B46.1 standard and the International Organization for Standardization (ISO) surface texture series of standards. The group's utilization of existing resources has been effective in recent projects, including those on standardized bullets and casings, hardness traceability, uncertainty reductions, and the calibration of Type-D roughness artifacts.

—The Large-Scale Coordinate Metrology Group developed a laser-tracker calibration system for the Naval Surface Weapons Center for application to missile launch from submarines. The group is investigating ways to precisely measure propeller dimensions while simultaneously machining the propeller. These sorts of collaborative projects keep NIST at the forefront of large-scale metrology.

—The Engineering Metrology Group's M48 Moore Special Tool CMM is world-leading, with an error of 1 micrometer or less anywhere in its volume. It is used for length traceability and for evaluation of two-dimensional CMM traceability artifacts and other calibrations. The group's gage block calibration capability is world-class, and ongoing research into the effects of deformation and surface finish are maintaining this traceability program at this level.

- *Within the Manufacturing Metrology Division:*

—The work on microforce measurements represents significant progress. Its impact is significant, the technology challenges have been clearly identified, and a detailed technical plan has been developed. This project is progressing toward establishing the reference standard for small force measurement.

—The advanced optics metrology program is well focused on areas of significant need and is of high technical quality. The XCALIBIR project is focused on an area of significant metrology need in semiconductor manufacturing. The laboratory capability and technical results are world-class.

—Significant collaborative work is being successfully performed in the mass measurement arena using the Silicon Sphere.

- *Within the Intelligent Systems Division:*

—The competence development and infrastructure program develops fundamental competence in areas of broad relevance to the division. It also provides a framework within which intelligent systems technologies can be evaluated, specified, and integrated by the manufacturing industry.

—The division's accomplishments on Department of Defense unmanned ground vehicles (UGVs) include successful demonstrations of NIST real-time control (RTC) controlled robotic vehicles and the publication of a reference model architecture for UGVs. The NIST team is among the world leaders in UGV technology.

—Work on the development of an interoperability testbed for intelligent open architecture manufacturing systems is of high quality.

- *Within the Manufacturing Systems Integration Division:*

—The division is engaged in high-quality work at several levels of abstraction in system integration capabilities: standards and measurements, process representation, integration, modeling capabilities, and the use of software to enhance manufacturing performance.

—The interoperability project is well planned and represents a best-practice area demonstrating creative application of the principles of logic.

Significant opportunities in the MEL for further progress and development of technical work include these:

- Achieving an improved process of planning and of continual process improvement, as well as improved reporting technical merit through a more consistent program and project planning format that describes a time line and schedule for a project, includes a budget and financial summary, and provides a summary of critical issues and interdependent steps planned.
- Expanded collaboration with other national engineering laboratories. Examples might include the University of Michigan and Sandia National Laboratories for reference testing; Ohio State University and the University of Illinois for predictive process engineering; and ISO TC213, ASME B89, Applicon Bravo, PTC (ProNC), and Lockheed Martin for STEP-NC (STEP—numerical control) and STEP-CMM. Partnership with the Oak Ridge Y12 Metrology Laboratory could be explored to provide CMM calibration service during the move to the Advanced Measurement Laboratory and on an ongoing basis.
- Performing industrial deployment tracking that involves user penetration and an emphasis on manufacturing engineering partnership, taking the STEP project as a good benchmark.

Program Relevance and Effectiveness

The Manufacturing Engineering Laboratory has a unique role to play in U.S. manufacturing through its expertise in measurements and standards. Generally the work of MEL is both relevant to the needs of customers (industry, government, and/or other NIST laboratories) and performed and disseminated effectively. Examples include the following:

- *Within the Precision Engineering Division:*

—The Nanoscale Metrology program extends dimensional metrology to the submicron scale, providing standards, measurement capability, and measurement uncertainty guidelines for the semiconductor and nanotechnology industries.

—Advances in fundamental scanning electron microscopy and optical microscopy are of value to industry in both critical dimension and overlay metrology.

—Through work on the Advanced Metrology Advisory Group (AMAG) 4 benchmarking wafer, a joint ISMT/NIST project, researchers have played a significant role in establishing a common artifact for SEM, scatterometry, electrical probe comparisons, and line-edge roughness evaluations.

—The surface and microform metrology work has produced significant contributions to national and international standardization for surface metrology, including the ASME-B46.1 and ISO surface texture series of standards. Utilization of existing resources has been effective in recent relevant projects, such as standardized bullets and casings, hardness traceability, uncertainty reductions, and the calibration of Type-D roughness artifacts.

—The engineering metrology work manages and reduces the uncertainty contribution of the traceability of length, location, spacing measurements, and other traditional geometric and dimensional tolerancing (GD&T)-type dimensional controls (e.g., roundness, cylindricity, perpendicularity, and angle). This resource is used by many customers.

—The large-scale metrology work characterizes, evaluates, and improves instruments that measure coordinates at lengths greater than 1 m. Collaborative projects keep NIST at the forefront of large-scale metrology and boost industrial productivity.

- *Within the Manufacturing Metrology Division:*

—In its role as the nation's reference laboratory for the units of mass, force, vibration, and sound pressure, MMD provides calibration services, develops advanced methods for mechanical metrology, and develops national and international standards. This role is critical for the nation's manufacturing industry for distributed international manufacturing and commerce. The division retains world-class capabilities and has state-of-the-art facilities for a number of metrology services, including the XCALIBIR and the Microforce projects.

—The division acts as a catalyst for collaborative efforts in manufacturing and mechanical metrology technology among government, industry, and academia.

- *Within the Intelligent Systems Division:*

—The Critical Infrastructure Protection program is relevant to the homeland security efforts, especially the need for protection of the nation's infrastructure.

—The Intelligent Open Architecture Control of Manufacturing Systems program has relevance to U.S. Army and homeland security needs; its fundamental aspects can and should be applied to manufacturing as well.

- *Within the Manufacturing Systems Integration Division:*

—The division manages both basic research and applied research and development tasks well in service to customers in government, academia, and industry.

—MSID is heavily engaged in work on interoperability issues, addressing how rapidly changing components of the manufacturing enterprise work together. The rapid and accelerating pace of change encourages manufacturing engineers to work with MSID, which fills a niche in the manufacturing environment not filled by other university, national laboratory, or vendor programs.

—The division's direct impact on the manufacturing customer base can be significant. As one example, MSID's involvement in STEP, a highly visible and highly successful program that has saved industry approximately a billion dollars, was essential to this program's success.

The prestigious Department of Commerce Gold Medal was awarded to a staff member for his fundamental advances in the science and technology of the fabrication and dimensional and electrical characterization of nanoelectronic devices, and the Bronze Medal was awarded to a division team for outstanding support and technical contributions in the fabrication and assembly of the Charters of Freedom encasements that protect the parchments of the Declaration of Independence, the Constitution, and the Bill of Rights. These awards, along with others (e.g., the Jacob Rabinow Applied Research Award to the team working in applications of robotics to unmanned ground vehicles; the Judson C. French award to the team providing mass metrology calibration services and to a division member responsible for achievement in the development of national traceability for the Rockwell C-Scale Hardness Test; a Crittendon Award in recognition of a division member's superior technical instrument manufacturing and customer service; and additional external awards), provide evidence of the recognized effectiveness of the research done in MEL.

TABLE 3.1 Sources of Funding for the Manufacturing Engineering Laboratory (in millions of dollars), FY 2000 to FY 2003

Source of Funding	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (actual)	Fiscal Year 2003 (July 2003 estimate)
NIST-STRS, excluding Competence	27.3	29.1	30.7	32.5
Competence	1.1	1.0	0.6	0.4
ATP	1.8	1.3	1.3	1.5
Measurement Services (SRM production)	0.1	0.1	0.1	0.1
OA/NFG/CRADA	6.1	6.1	6.9	5.1
Other Reimbursable	5.1	5.1	5.2	5.0
Total	41.5	42.7	44.8	44.6
Full-time permanent staff (total)[a]	232	211	204	202

NOTE: Funding for the NIST Measurement and Standards Laboratories comes from a variety of sources. The laboratories receive appropriations from Congress, known as Scientific and Technical Research and Services (STRS) funding. Competence funding also comes from NIST's congressional appropriations but is allocated by the NIST director's office in multiyear grants for projects that advance NIST's capabilities in new and emerging areas of measurement science. Advanced Technology Program (ATP) funding reflects support from NIST's ATP for work done at the NIST laboratories in collaboration with or in support of ATP projects. Funding to support production of Standard Reference Materials (SRMs) is tied to the use of such products and is classified as "Measurement Services." NIST laboratories also receive funding through grants or contracts from other [government] agencies (OA), from nonfederal government (NFG) agencies, and from industry in the form of cooperative research and development agreements (CRADAs). All other laboratory funding, including that for Calibration Services, is grouped under "Other Reimbursable."

[a]The number of full-time permanent staff is as of January of that fiscal year.

Laboratory Resources

Funding sources for the Manufacturing Engineering Laboratory are shown in Table 3.1. In January 2003, staffing for the laboratory included 202 full-time permanent positions, of which 134 were for technical professionals. There were also 25 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers. The decline in staff continues to represent a significant area of concern, requiring careful management of priorities. This problem will continue to require thoughtful planning about which projects to begin and which to close.

MEL's funding remains flat relative to previous years. While this results in constraints, including the inability to maintain personnel levels (as cost per individual rises annually), a flat budget is, relative to budgets experienced by the industrial sector in the current economy, enviable. Nonetheless, the fact that the full-time permanent staff of the laboratory has shrunk in the past several years continues to present considerable challenges for MEL management as it seeks to address technical goals, objectives, and priorities of the laboratory.

While recognizing the challenge of managing under such difficult resource constraints, the panel in last year's report suggested that MEL could improve the use of its resources through more specific resource planning, and that progress in MEL strategic planning should be made to match MEL's resource planning. The panel suggested at that time the need for a resource plan that encompasses human resources, equipment, and facilities and that is integrated with the MEL strategic plan to ensure that resources are available for and directed toward the laboratory's highest-priority programs. MEL's FY 2003 strategic plan has incorporated a number of these elements; the panel commends that effort. It suggests further that graphical time line representation (showing planned milestones, project subgoals, and interdependencies of project activities) for major programs and activities (e.g., the move to the Advanced Measurement Laboratory) would provide detail that the panel requires in order to offer more constructive feedback.

The panel previously suggested that MEL define a plan for predicting the mix of skills it will need in order to achieve major objectives and that it chart how to maintain or obtain these skills. The panel recognizes that no manager can perfectly predict retirements, separations, or available new hires, but anticipating these events to the extent feasible and developing a strategy to ensure that the necessary skill mix is available for the future will help increase the effectiveness of MEL's use of resources and of its programs overall. MEL should perform an analysis to determine an effective balance between administrative staff and technical staff and also between managers and bench-level staff.

The matrix management approach that MEL has taken to meeting its programmatic objectives is appropriate, and staff seem to have adapted well to matrix management. MEL management has taken steps to assure that staff are assessed by supervisors who are familiar with their project requirements and accomplishments.

Existing equipment within MEL is generally acceptable. The laboratory has prepared a detailed document providing information on equipping the AML, although a summarized presentation of its key information would be helpful. The AML offers the capability to do world-class work in a number of important areas; its construction and equipment moves are considered by MEL to be on schedule and within budget. MEL should be sure to provide timely and effective avenues of replacement and backup services for equipment that is taken out of service during the move.

Laboratory Responsiveness

The panel continues to observe a high level of cooperation and commitment from MEL staff. The broadening of the MEL mission statement (removing the restriction to support discrete-parts manufacturers) continues to be well aligned with areas of growth and opportunity. Matrix management appears to be a successful MEL strategy for managing increasingly collaborative activities.

MEL has made responsive progress in attending to its customer focus—which should be extended to interactions with industry and government personnel at higher organizational empowerment levels than those of the technical, scientific, and engineering staff that form the great majority of MEL's external interactions. MEL has also made progress in strategic and program planning, which would improve further with the application of standard program planning tools that yield clear definitions and descriptions of milestones and accomplishments. There are opportunities for MEL to refine strategic plans and themes to achieve clarity of alignment with the NIST Strategic Focus Areas.

4

Chemical Science and Technology Laboratory

PANEL MEMBERS

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Alan Campion, University of Texas, Austin, *Vice Chair*
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Jeffrey B. Bindell, University of Central Florida
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Peter Wilding, University of Pennsylvania Medical Center
Jerome J. Workman, Jr., Argose Inc.

Submitted for the panel by its Chair, James W. Serum, and its Vice Chair, Alan Campion, this assessment of the fiscal year 2003 activities of the Chemical Science and Technology Laboratory is based on site visits by individual panel members, a formal meeting of the panel on February 25-26, 2003, in Gaithersburg, Maryland, and documents provided by the laboratory.[1]

[1]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Chemical Science and Technology Laboratory: Annual Report FY2002*, NISTIR 6954, National Institute of Standards and Technology, Gaithersburg, Md., February 2003.

LABORATORY-LEVEL REVIEW

The Chemical Science and Technology Laboratory (CSTL) is the nation's reference laboratory for chemical measurements. Its mission is to provide a chemical measurement infrastructure to support and enhance U.S. industry's productivity and competitiveness; assure equity in trade; and improve public health, safety, and environmental quality. The laboratory is organized in five divisions: Biotechnology, Process Measurements, Surface and Microanalysis Science, Physical and Chemical Properties, and Analytical Chemistry (see Figure 4.1). Following the panel's major observations from this year's review, this chapter presents an overall assessment of the laboratory. Chapter 11 provides division-level assessments, with detailed discussions of some of the more noteworthy projects.

Major Observations

The panel presents the following major observations from its assessment of the Chemical Science and Technology Laboratory:

- CSTL's research and standards programs are technically excellent overall, with many considered to be world-class by the scientific and technical community in general and by international standards

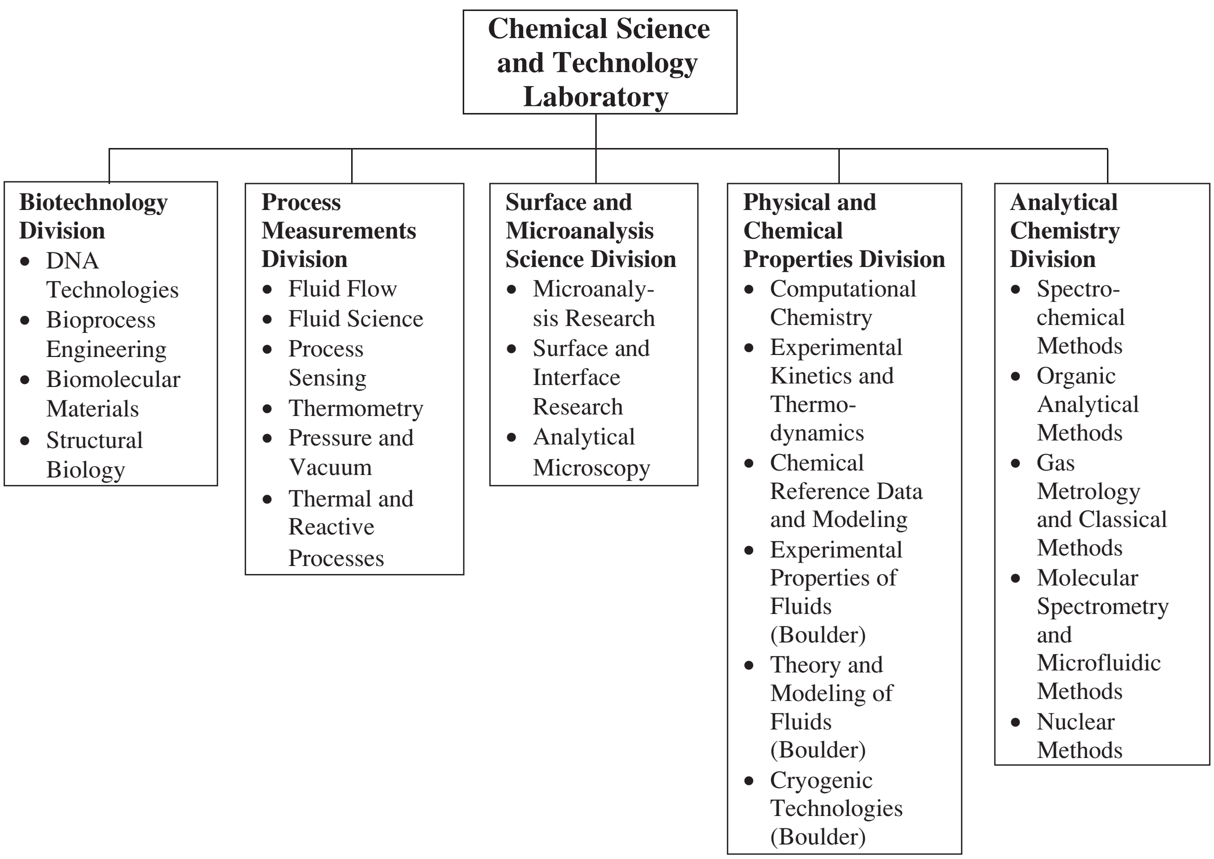

FIGURE 4.1 Organizational structures of the Chemical Science and Technology Laboratory. Listed under each division are its division's groups.

organizations in particular. The laboratory's outstanding performance in the Key Comparisons of National Metrology Institutes (NMIs) conducted under the auspices of the CIPM (Comité International des Poids et Mésures) is a particularly fine example of CSTL's capabilities.

- CSTL has clearly demonstrated both the relevance and effectiveness of its programs to its customers, primarily U.S. industry, government, and academia, but also to international science, technology, and commerce. Evidence of the impact of its work includes customer feedback from symposia and workshops, formal economic impact studies, and documented leadership in the international standards community.
- Even during an extended period of flat budgets, the laboratory's innovative practices and successful partnering have sustained exceptional productivity and the continuation of its high visibility, recognition, and world leadership in the development of measurement standards. In particular, the panel cites significant advances in the clinical in vitro diagnostics (IVD) and NIST-Traceable Reference Materials (NTRM) programs. Having commercial facilities produce NIST-traceable gas standards is an excellent example of creative leveraging of CSTL's efforts.
- CSTL has implemented an excellent strategic planning process that is closely aligned with the goals and objectives of the overall NIST strategic plan (the NIST 2010 plan) and that has enabled it to effectively anticipate future customer needs. Linking the annual operating plan tightly and transparently to the strategic plan has been an excellent management decision that allows the laboratory to effectively plan its ongoing programs while responding to unanticipated needs and opportunities.
- The panel encourages the development of a coherent plan for responding to the explosive growth of opportunities for the Biotechnology Division. In particular, it is not clear that there currently exists enough in-house expertise in the biological sciences to guide and support the development of programs in this field.
- Standard Reference Material (SRM) productivity could be enhanced by building stronger in-house collaborations.
- The Analytical Chemistry Division continues to be central to the laboratory's standards development. The panel is concerned, however, that declining support for personnel and equipment will ultimately erode both quality and productivity and encourages the laboratory to develop a plan to ensure the successful continuation of the important work conducted by this group.
- CSTL has made great progress in Web site design and information dissemination; as indicated in last year's report, however, there remain lapses in data updates that detract from the utility and value of these sites. Also, the panel recommends that over the course of the next year the laboratory develop common entry points for all of the chemical information available on its site, perhaps using a search engine format similar to that of the Chemical Abstract Services Syfinder.
- While the panel is encouraged with the small increase in laboratory funding over the past year, it is concerned that proposed federal reductions in Advanced Technology Program funding will require nontrivial repositioning of the laboratory programs. CSTL should address this issue explicitly in its strategic and operational planning processes.

Technical Merit

The technical merit and quality of CSTL's work continue to be excellent, in many cases world-class. Its performance in the CIPM Key Comparisons is probably the finest single example of its stature in the national measurements community. The panel also wishes to draw attention to several other examples that illustrate the outstanding, ongoing quality and technical merit of CSTL projects, including these:

- Significant advances in clinical markers technologies and the completion of several SRMs for IVD;
- Significant advances in the rigorous validation of biomarkers for health diagnostics;
- Significant advances in the research on properties and equation-of-state of fluid mixtures near the critical point, and the release of an updated version of the NIST database REFPROP (alternative refrigerants);
- Development of the extensible markup language (XML) data format for spectroscopic hyperdata. This general data format enables very impressive methods for spectral data storage and analysis and is destined to become a nationally accepted standard format;
- Demonstration of a 10,000-fold improvement in the sensitivity of microfluidic sensors;
- A major update of the NIST Mass Spectral Database, which is among NIST's most widely disseminated Standard Reference Databases (SRDs); and
- Successful completion of a Johnson Noise Thermometer prototype and documentation of a noise-to-power accuracy ratio of better than 0.1 percent over the range considered. The panel views the ability to recalibrate these sensors remotely—for example, for space station applications—as very significant.

Program Relevance and Effectiveness

CSTL continues excellent practices to ensure that its technical programs are relevant to the needs of its customers. Various mechanisms are used to gather outside input on current or planned activities; these include participation in standards committee meetings, technical conferences, benchmarking and roadmapping activities, professional society meetings and committees, and trade organization events. Staff members take lead roles in organizing these gatherings and often hold them at NIST. Researchers maintain informative relationships with a large number and wide variety of guest researchers and collaborators in industry and at universities to support and leverage their work.

Overall, the programs of CSTL have a strong impact on a wide array of industries and research communities. CSTL's contributions often provide critical bridges between research directed toward the short-range goals of industry and the long-range, open-ended inquiries pursued in universities. Particularly noteworthy for their relevance and effectiveness are the laboratory's efforts in SRMs, SRDs, and international standards activities. These services and activities rarely garner headlines, but they underpin many critical measurements in the chemical, pharmaceutical, medical, and other industries and are therefore very highly leveraged investments. Finally, CSTL responded quickly and decisively to recent national crises and is actively assessing its current capabilities and planning for possible future contributions to the national homeland security effort. The panel wishes to highlight the following programs for their significant impact:

- Widely recognized leadership in the development of clinical standards and diagnostic devices, ensuring continued U.S. dominance in an area fostering more affordable health care at home and abroad. New methods developed by CSTL for the amplification and automated detection of DNA fragments served a critical need in the identification of victims of the World Trade Center disaster. This technology could be the basis of a multitude of applications existing in the military and supporting homeland security requirements.
- The frequency of visits to the NIST Chemistry WebBook site (an increase of 43 percent in 2002) and the inclusion of databases in commercial instrument packages. Roughly one-half of all gas chromatography/mass spectrometry instruments sold worldwide include the CSTL Mass Spectral Database,

enabling the application of these techniques to problems that span nearly every area of science and technology.

- The pursuit of DNA diagnostics for the detection of human disease in the NIST/National Cancer Institute (NCI) Biomarker Validation Laboratory. This NIST component of the NCI Early Detection Research Network (EDRN) serves to refine recently discovered cancer biomarkers and to format new research tests for field trials in EDRN clinical laboratories. Significant advances are now being made in the areas of breast and prostate cancer and in the identification of clinical markers for radiation damage and processes involved in aging.
- The development of an XML data format for spectroscopic hyperdata in the transmission electron microscope (TEM) laboratory is extremely important work. This general data format supports very powerful methods of spectral data storage and analysis and is destined to become a nationally accepted standard format. These data are critically important in almost every area of science, technology, and manufacturing.
- Developments in microheater sensors have reduced detection limits to as low as 20 to 200 ppb for sarin; these sensors can also detect mustard gas and GA-tabun with a response time of approximately 50 seconds. A new, monolithic preconcentrator may further increase sensitivity by an additional factor of 10. Carbon nanotubes have been grown on MEMS micro-hotplates, enabling the evaluation of their performance as gas sensors. This project is relevant to both homeland security and Chemical Weapons Convention defense technologies.

Laboratory Responsiveness

CSTL provided a detailed, written, point-by-point response to the observations and recommendations made in the FY 2002 assessment. The panel is, in general, quite satisfied with the laboratory's response. Many recommendations were implemented, and thoughtful replies were provided in cases in which management either could not implement a suggested change (usually for resource or NIST-wide structural reasons) or chose a different solution based on its own programmatic priorities and resources. A few examples of the kinds of laboratory responses include the following:

- Determined efforts to bring all calibration programs into compliance with ISO/IEC 17025 have resulted in significant progress and already rate highly in the eyes of calibration service customers. It would be especially beneficial for NIST to publish its ISO-compliant quality manual and other relevant quality documents on the Web. Commercial and government calibration and testing laboratories could use such documents for a variety of purposes, including use as guides and templates for their own documents.
- The panel is pleased to note that the laboratory has started to address the issue of management training for group leaders; this is an important issue, given the broad range of responsibilities now assigned to group leaders and the general lack of training in these areas in the careers of scientists and engineers.
- The panel was pleased to see the reorganization of the effort in atmospheric chemistry in the Surface and Microanalysis Science Division in response to repeated suggestions by the panel over several years.
- Some responses to the FY 2002 recommendations were not as strong as those noted above. For example, progress in providing timely Web updates and more interactive site designs continues to be slow. The dissemination of new knowledge and data generated by the laboratory is critical to its continued success and utility; now that the Web is the dominant point of contact between NIST and its

customers, it is imperative that the Web site be an efficient and easy-to-use interface. If resource limitations at the laboratory level are indeed the constraint to more rapid progress, the panel urges management to work collaboratively with the directors of the other laboratories and with the NIST Director's Office to address this NIST-wide issue of great importance.

Laboratory Resources

Funding sources for the Chemical Science and Technology Laboratory are shown in Table 4.1. In January 2003, staffing for the laboratory included 271 full-time permanent positions, of which 234 were for technical professionals. There were also 81 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Although there is a small increase in CSTL funding for FY 2003, mandatory salary increases will translate once more into an essentially flat budget. Within this environment, hard choices have had to be made, involving trade-offs between personnel and laboratory equipment. The loss of five professional staff in one division during 2002 has heightened the panel's concern over the trend in reduction of full-time-equivalent personnel. As in the previous assessment, the panel observed too many priority projects with subcritical resources devoted to them. Given that an era of flat budgets has taken hold, the panel strongly advises the laboratory to take a hard look at its priorities and examine areas in which potential

TABLE 4.1 Sources of Funding for the Chemical Science and Technology Laboratory (in millions of dollars), FY 2000 to FY 2003

Source of Funding	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (actual)	Fiscal Year 2003 (July 2003 estimate)
NIST-STRS, excluding Competence	37.7	36.9	38.3	45.1
Competence	2.4	1.9	2.7	2.7
ATP	3.3	3.2	2.5	2.1
Measurement Services (SRM production)	2.2	1.9	2.6	2.2
OA/NFG/CRADA	14.2	14.3	12.4	10.7
Other Reimbursable	3.4	5.8	6.1	6.3
Total	63.2	64.0	64.6	69.1
Full-time permanent staff (total)[a]	275	264	273	271

NOTE: Funding for the NIST Measurement and Standards Laboratories comes from a variety of sources. The laboratories receive appropriations from Congress, known as Scientific and Technical Research and Services (STRS) funding. Competence funding also comes from NIST's congressional appropriations but is allocated by the NIST director's office in multiyear grants for projects that advance NIST's capabilities in new and emerging areas of measurement science. Advanced Technology Program (ATP) funding reflects support from NIST's ATP for work done at the NIST laboratories in collaboration with or in support of ATP projects. Funding to support production of Standard Reference Materials (SRMs) is tied to the use of such products and is classified as "Measurement Services." NIST laboratories also receive funding through grants or contracts from other [government] agencies (OA), from nonfederal government (NFG) agencies, and from industry in the form of cooperative research and development agreements (CRADAs). All other laboratory funding, including that for Calibration Services, is grouped under "Other Reimbursable."

[a]The number of full-time permanent staff is as of January of that fiscal year.

in-house funding resources may exist. One area suggested is charges for database use. Such an activity would require backing from comprehensive evaluations of cost and usage issues. Another area suggested for examination is optimization of professional-to-support staff ratios. Also in the line of restrained budgets, the laboratory director should exert even greater effort to keep researchers informed of pending programmatic realignments and perhaps even to invite their input as decisions are being made. This would not only serve to increase morale but would also be a resource for new ideas based on the experiences of the staff.

Facilities and instrumental infrastructure in CSTL are very good overall. Updates in the elevators and exhaust hoods in some buildings have improved the working environment. The panel was pleased to hear that some funding has at last become available to begin repairs on the Boulder facility. Two important pieces of equipment, the electron microprobe and the Auger spectrometer, remain in need of attention to be brought online. It is still not clear when the CSTL equipment will be moved to AML.

5

Physics Laboratory

PANEL MEMBERS

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Submitted for the panel by its Chair, Duncan T. Moore, and its Vice Chair, Robert L. Byer, this assessment of the fiscal year 2003 activities of the Physics Laboratory is based on site visits by individual panel members, a formal meeting of the panel on February 11-12, 2003, in Gaithersburg, Maryland, and documents provided by the laboratory.[1]

[1]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Physics Laboratory*, NISTSP 994, National Institute of Standards and Technology, Gaithersburg, Md., February 2003.

LABORATORY-LEVEL REVIEW

This chapter presents an overall assessment of the Physics Laboratory, beginning with the panel's major observations from this year's review. Chapter 12 provides division-level assessments.

The Physics Laboratory describes its mission as supporting U.S. industry by providing measurement services and research for electronic, optical, and radiation technologies. It is organized in six divisions: the Electron and Optical Physics Division, Atomic Physics Division, Optical Technology Division, Ionizing Radiation Division, Time and Frequency Division, and Quantum Physics Division (JILA). The organizational structure of the Physics Laboratory is shown in Figure 5.1.

Major Observations

The panel presents the following major observations from its assessment of the Physics Laboratory:

- The Physics Laboratory continues its tradition of technical excellence in the development and dissemination of precise metrics related to physical processes and in the experimental and theoretical contributions that it makes toward improving the understanding of fundamental physical principles.
- The laboratory's capital equipment budget is currently insufficient to support needed upgrades to the sophisticated instruments that are fundamental to its mission.
- The Physics Laboratory must continue to develop a strategic planning and prioritization process that results in clear laboratory goals and priorities, which can be used to allocate resources, determine program prioritization, and produce enhanced program focus and effectiveness. The panel observed little response to its recommendation from last year's report that strongly encouraged further development of the laboratory's strategic plan. The panel reiterates its recommendation that the current strategic plan for the Physics Laboratory be updated and that it be made available for review during the next assessment period.
- The division chiefs should exert more effort in communicating clear laboratory goals to the staff in order to improve morale and reduce uncertainties that accompany restricted budget environments.
- There is confusion within the staff concerning intellectual property. The laboratory needs to enunciate a simple and clear philosophy and policy concerning intellectual property and how it affects performance. This information and procedures for disclosure and patenting of inventions should be clearly communicated to the staff.
- Responses of the laboratory to the national homeland security initiative have been excellent. This work has resulted in a shift of emphasis of some programs and loss of personnel which, unless longer-term resources are provided, will be detrimental to ongoing programs.
- The staff retirement in the Time and Frequency Division leaves a vacancy that will seriously affect the implementation of its work. The laboratory should respond rapidly with a plan that will keep the affected efforts current and continuing.
- The Ionizing Radiation Division should expand its activities in the medical radiation communities to support the development of usage protocols and to implement their institutionalization. A person is needed to champion efforts related to the recently acquired medical accelerator.
- The panel appreciates the new meeting format this year but suggests that future speakers limit the number of viewgraphs used in order to keep presentations within the time scheduled and to permit a period for questions and discussion.

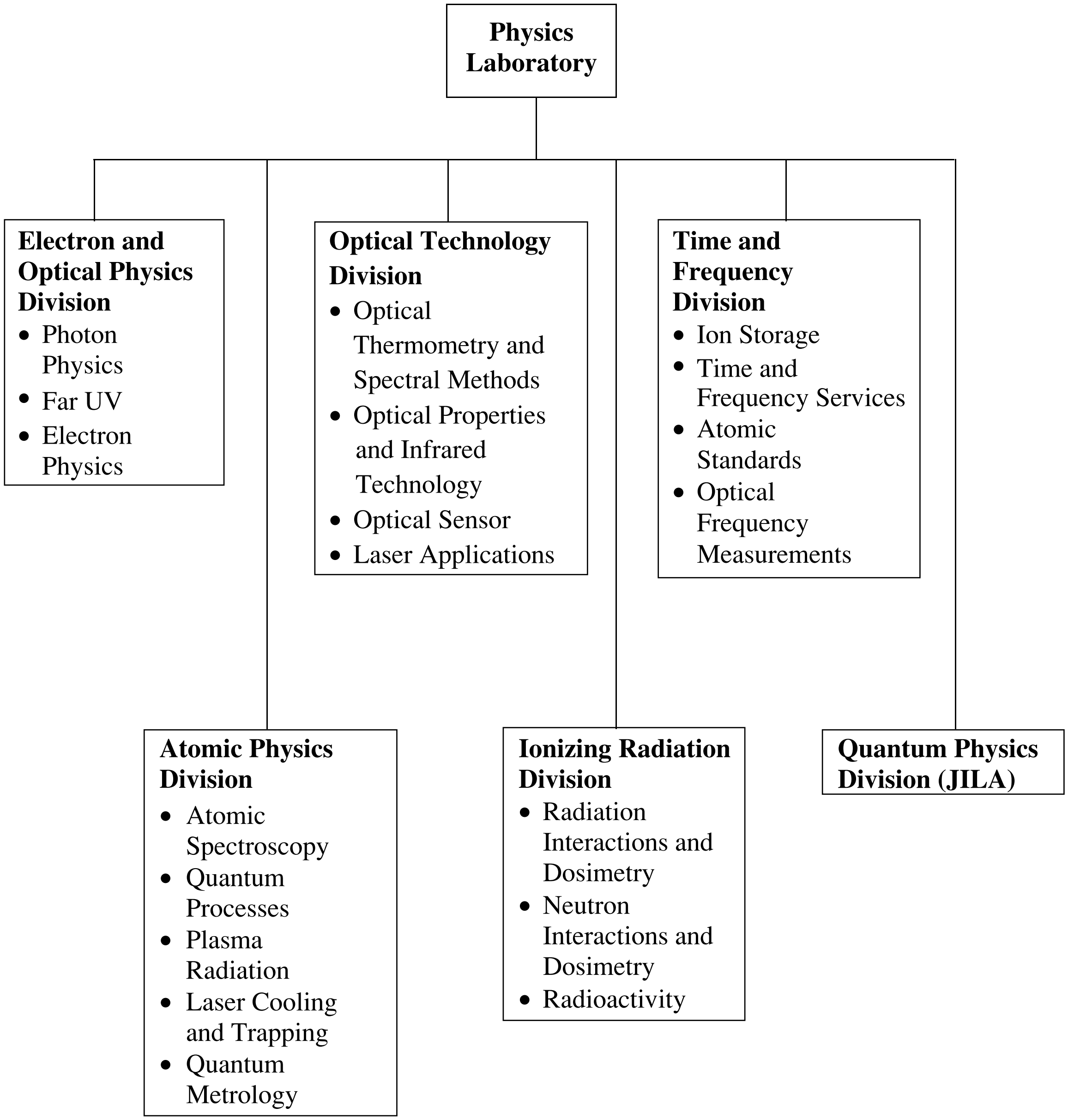

FIGURE 5.1 Organizational structure of the Physics Laboratory. Listed under each division except Quantum Physics (JILA) are the division's groups.

Technical Merit

The NIST Physics Laboratory has long been known among its technical peers for the outstanding level of its scientific research. The laboratory has a tradition of world leadership in many of its areas of activity. Overall, its researchers are well known for the originality of their work, their ability to carry out difficult measurements to record levels of precision, and their deep understanding of the basic physical phenomena that underlie such measurements.

In its current assessment, the panel found that the Physics Laboratory continues its tradition of outstanding, original, scientific research and application of rigorous experimental and theoretical approaches to maintain record levels of precision and accuracy in measurements of physical phenomena. The panel continues to be impressed with the quality and the quantity of top-notch scientific results reported in papers published in leading peer-reviewed scientific journals and in presentations and invited talks at leading technical conferences. Such reporting gives testimony to the technical merit and high level of respect accorded to NIST scientists and their work by the scientific community. The laboratory has made many notable technical advances this year, as discussed in the division reviews in Chapter 12. Some examples of achievements illustrating the excellent quality and technical merit of this work are highlighted below:

- Significant progress has been made this year on the "atom on demand" effort, which involves capturing single atoms in a magneto-optical trap and then moving them with lasers. A high-power CO_2 laser has been acquired to extract atoms from the source. The next steps are to assess the viability of this approach and then to place atoms into specific magnetic traps. While operating in the realm of nanoscience, this work has the potential objective of creating quantum computing architectures.
- The definition of a universal logic gate, the so-called geometric phase gate, has been completed. This gate appears to substantially ease requirements on lasers, for example, and is well suited to scaling the systems to larger numbers of ions, which in turn offers the potential for realizable large-scale quantum computers.
- Considerable progress has been made in several areas addressing the continuous refinement of time and frequency measurements. NIST continues to define the state of the art in these measurements and, along with the Physikalisch-Technische Bundesanstalt (PTB) in Germany, is considered first in primary frequency standards performance. Last year's clock comparison with PTB was the best ever, at 5 parts in 10^{-16}. Improvements accomplished this year in the understanding of systematic and environmental effects on two-way time transfer support this effort.
- The electron beam ion trap (EBIT) team continues to be a leader in studies of the fundamental properties of highly charged ions for both fundamental science and its applications. Ongoing measurements of the properties of optical materials at the 157-nm wavelength is fundamental to future-generation vacuum ultraviolet (VUV) lithography for integrated circuits. Discovery of the original birefringence phenomenon and of methods for its avoidance has brought substantial outside recognition to the group.
- Recent demonstration of the Bose condensate in Cs gas and work on coherent manipulation of collisions in Bose-Einstein condensates (BECs) permit new insights into the production of ultracold molecules and also seed new concepts for neutral-atom quantum computing. This work is carried out by one of the few theoretical atomic, molecular, and optical physics groups in the United States; as such, the Quantum Processes Group is a national resource and leader.
- The expertise of the laboratory is recognized as supporting several important areas of homeland security. As a member of the Mail Security Task Force of the White House Office of Science and Technology Policy (OSTP), the Ionizing Radiation Division has been working on sanitizing mail contaminated by anthrax during bioterror actions and on associated issues. In the current year appropriate radiation dosages for parcel packages have been validated, and it has been determined that DNA profiling is still possible following mail irradiation. Other ongoing efforts in this area include the examination and development of high-energy X rays for cargo inspections.
- Continued development of surface-sensitive optical methods pioneered at the laboratory has had a significant impact on priority areas, from semiconductor technology to biotechnology, as well as on

inherent scientific understanding. These contributions are having a marked impact on laboratories throughout the world. Recent advances have included the use of doubly resonant (vibrational and electronic) excitation to enhance the sensitivity and selectivity of these methods. Studies of chemical groups in DNA monolayers have successfully demonstrated the technique.

Program Relevance and Effectiveness

The Physics Laboratory continues to reach out through a variety of efforts to ensure that its programs are responsive to customer and national needs and that reliable experimental and theoretical information is maintained to support emerging technological and scientific directions. These approaches include individual interactions with customers, industries, and collaborating researchers, as well as the initiation of topical workshops and active involvement in technical conferences and consortia. As an example, the panel points out the activities of the Council for Optical Radiation Measurements (CORM). This council, originally instituted at NIST, evaluates national needs in optical metrology and provides feedback on the services and standards supplied by the Optical Technology Division. The colorimetry facility, for example, was developed in response to CORM recommendations.

Activities of the Ionizing Radiation Division in the area of homeland security have been particularly visible and commendable, resulting in immediate responses to sanitize mail contaminated by anthrax spores through bioterrorist activities that had the potential to stop mail service across wide areas of the country. The Ionizing Radiation Division continues to participate in a national task force aimed at keeping various forms of U.S. mail and archival documents safe. In the coming year, its division chief will be retained by the Department of Homeland Security in the areas of program evaluation and development. This assignment will provide further opportunities for the laboratory to align its resources for participating in this highly important national initiative. The panel further emphasizes observations on homeland security made by last year's panel: that is, the Physics Laboratory is now well positioned to accomplish NIST aims in homeland security and should develop an aggressive proposal in this area with appropriate federal and private partnerships.

The Physics Laboratory continues to serve as a central, impartial presence in metrology and calibrations for commercial and scientific technology development. Laboratories worldwide rely on its measurements for assessing time, frequency, radiation effects, radiological materials, and the behavior and properties of optical materials and phenomena. Thus the Physics Laboratory is a national scientific treasure.

In the present assessment the panel notes that little response has been made to the issues that were raised by last year's panel concerning the utility of the strategic plan that had been presented for the Physics Laboratory. Considerable discussion was devoted to this topic, as reflected in the paragraph from last year's report quoted here for reference:

> In last year's assessment,[2] the panel noted that clearly articulated strategic goals for the Physics Laboratory would improve program alignment with customer needs and facilitate more effective communication of program relevance both within NIST and to external stakeholders. The panel notes that, in response, the laboratory has developed a revised strategic plan, which is an important first step in strategic program management. The current plan, however, does not appear very useful. It appears to have been written by an outside consultant, with minimal involvement by division managers. The panel

[2]National Research Council, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2001*, National Academy Press, Washington, D.C., 2001.

> found little evidence of the plan's use for allocating resources relative to priorities and little indication that the divisions understand the laboratorywide goals and priorities enunciated in the plan. In some cases, divisions are receiving mixed signals about the importance of and the level of support for specific programs. The basis for the program prioritization presented in the plan itself remains unclear. The process of creating a strategic plan is probably more important than the final document itself—engaging division management and broad staff representation is necessary if the end result is to be clearly understood goals and priorities and better program focus, relevance, and effectiveness. The panel noted that each division is already carrying out strategic program management to at least some degree; these divisional efforts are the basis on which a useful laboratorywide strategy can be built.[3]

The panel reiterates its belief that strategic planning should be a continuous process in the laboratory's research agenda as a means to maintain the relevance and effectiveness of its programs.

Laboratory Resources

Funding sources for the Physics Laboratory are shown in Table 5.1. In January 2003, staffing estimates for the Physics Laboratory show 196 full-time permanent positions, of which 155 were for technical professionals. There were also 48 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Despite constrained budgets, the Physics Laboratory facilities still appear to sustain the laboratory's current projects. However, there is increasing concern over the lack of adequate funds for necessary building repairs and capital equipment purchases, upgrades, and maintenance. In the Time and Frequency Division, the cesium primary standard is housed in a laboratory with a leaky roof, and the test and measurements laboratory is hindered by radio-frequency and microwave signal interference that will likely limit the ability to conduct future noise measurements with needed sensitivities. Although the laboratory has responded remarkably to homeland defense needs, radiation equipment will require updating to meet the demands of newer radiologically based programs. The fact that funding for homeland security projects has not been allocated is creating a drain on other programs.

On the other hand, laboratory space for the Time and Frequency Division has improved markedly. Two new laboratories with exceptional environmental controls have been constructed. These laboratories, which will house the laser and quantum logic work, have the best environmental controls on the site. Old space will be renovated and used for the primary cesium clock fountains. New laboratory space for optical frequency measurements and the chip-scale atomic clock project will be completed soon. A plan exists to renovate all Time and Frequency Division laboratories over the next 10 years.

The Optical Technology Division is home to several unique pieces of instrumentation that underlie the mission of the division. Facilities maintained and developed by the division include the spectral irradiance and radiance calibration with uniform sources (SIRCUS), the high-accuracy cryogenic radiometer (HACR), the Synchrotron Ultraviolet Radiation Facility (SURF), and instrumentation for determination of the temperature scales in the high temperature range. The division has been able to provide ongoing resources not only to maintain existing facilities but also to upgrade them, with respect to both technical specifications and ease of operations. This trend is illustrated by the shift toward source-based radiometry and away from detector-based radiometry, the former being more convenient for the generation of transfer standards and ready calibration of commercial instrumentation.

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[3]National Research Council, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2002*, National Academies Press, Washington, D.C., 2002, p. 131.

TABLE 5.1 Sources of Funding for the Physics Laboratory (in millions of dollars), FY 2000 to FY 2003

Source of Funding	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (actual)	Fiscal Year 2003 (July 2003 estimate)
NIST-STRS, excluding Competence	33.0	33.0	34.0	40.6
Competence	1.6	1.8	3.1	2.3
ATP	1.9	1.9	2.2	2.2
Measurement Services (SRM production)	0.2	0.1	0.1	0.1
OA/NFG/CRADA	10.1	10.6	11.8	17.1
Other Reimbursable	3.6	4.2	4.4	4.6
Total	50.4	51.6	55.6	66.9
Full-time permanent staff (total)[a]	204	200	205	196

NOTE: Funding for the NIST Measurement and Standards Laboratories comes from a variety of sources. The laboratories receive appropriations from Congress, known as Scientific and Technical Research and Services (STRS) funding. "Competence" funding also comes from NIST's congressional appropriations but is allocated by the NIST director's office in multiyear grants for projects that advance NIST's capabilities in new and emerging areas of measurement science. Advanced Technology Program (ATP) funding reflects support from NIST's ATP for work done at the NIST laboratories in collaboration with or in support of ATP projects. Funding to support production of Standard Reference Materials (SRMs) is tied to the use of such products and is classified as "Measurement Services." NIST laboratories also receive funding through grants or contracts from other [government] agencies (OA), from nonfederal government (NFG) agencies, and from industry in the form of cooperative research and development agreements (CRADAs). All other laboratory funding, including that for Calibration Services, is grouped under "Other Reimbursable."

[a]The number of full-time permanent staff is as of January of that fiscal year.

Despite the laboratory's ambitious technical objectives, funding of the laboratory has been restrained, and the number of permanent employees is strictly limited. Further, steadily increasing overhead rates erode the ability to provide secure, long-term support for the laboratory's excellent permanent staff. To meet their goals, divisions are making use of personnel in various other budgetary categories, such as postdoctoral researchers, contract employees, and emeritus staff. The presence of scientists in nonregular job categories significantly extends the capabilities of the laboratory. At the same time, it provides for the needed flexibility to accommodate changes in funding level and program emphasis. This mode of operation appears to the panel to be effective, although care must be taken to avoid losing critical expertise within the permanent staff. Oftentimes, some critical technical expertise resides in a single staff member whose departure could have a significant impact on current programs.

The Atomic Physics Division has been strongly affected by the redirection of its resources to homeland security efforts. In particular, the Quantum Metrology Group transferred 20 percent of its base funding to another division, and it lost the group leader to retirement and another staff member to homeland security activities. These actions have led to a critical situation for the group, and the anticipated replacement of these resources has not occurred. Remaining group staff members are early in their careers and very enthusiastic about the work they are performing. To maintain the group, a more aggressive hiring plan needs to be developed, to include not only permanent staff but also postdoctoral associates and/or visiting scientists, or other creative approaches to increasing staff numbers.

The key resource for the laboratory is, of course, its technical workforce. In its discussions the panel found, in accordance with recent laboratory-wide surveys, that the level of morale was high. Other than concern about the tight budgets and significant budgetary uncertainties associated with the outlook for the Advanced Technology Program and other programs, the panel did not identify major personnel issues.

Laboratory Responsiveness

Overall, the Physics Laboratory has been responsive to the recommendations of previous reports. The primary recommendation in recent years was to improve the focus of programs through clearly articulated, overall strategic goals. The panel's FY 2002 assessment noted that the laboratory had taken the first step toward responding to this recommendation, and the panel commended the laboratory for its leadership role in the NIST-wide health care initiative. In the current year, the laboratory is working with the University of Maryland to tap into its computational physics strengths in an effort to augment the laboratory's capabilities for the establishment of new funding opportunities. While this effort has not yet established new work, the panel believes that the association can be highly beneficial in the long run. Other responses within the divisions have contributed to the overall health of the laboratory. Two examples are discussed below.

The Electron and Optical Physics Division has responded energetically to last year's recommendations. The Far UV Physics Group has acquired and is testing a photoelectron microscope, and it is also working to further exploit the unique capabilities of SURF III for producing spectrally pure and easily tunable photons in the 3- to 5-eV energy interval.

A continuing concern over the past several years has been the long-term viability of the Atomic Spectroscopy Group, given its aging staff, inadequate funding, and the lack of enthusiasm for its strategic mission at high levels of NIST management. In last year's report the panel expressed significant concerns on this subject. As of this year's review, the prognosis for the group appears much improved. The Atomic Spectroscopy staff now includes several young members who can be easily viewed as forming the future core of the group. The energy and passion of these younger scientists are evident and contribute to the optimism of the group as a whole. The laboratory has provided a basic level of funding, and the group has had a successful year in attracting new grant funding from various sources. Although the group is not growing dramatically, at least its situation has stabilized, and its outlook for the future is brighter.

6

Materials Science and Engineering Laboratory

PANEL MEMBERS

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Submitted for the panel by its Chair, David W. Johnson, Jr., and its Vice Chair, Katharine G. Frase, this assessment of the fiscal year 2003 activities of the Materials Science and Engineering Laboratory is based on site visits by individual panel members, a formal meeting of the panel on March 13-14, 2003, in Boulder, Colorado, and documents provided by the laboratory.[1]

[1]Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Ceramics Division: FY2002 Programs and Accomplishments*, NISTIR 6904, National Institute of Standards and Technology, Gaithersburg, Md., September 2002. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Materials Reliability Division: FY2002 Programs and Accomplishments*, NISTIR 6905, National Institute of Standards and Technology, Gaithersburg, Md., September 2002. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Polymers Division: FY2002 Programs and Accomplishments*, NISTIR 6906, National Institute of Standards and Technology, Gaithersburg, Md., September 2002. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Metallurgy Division: FY2002 Programs and Accomplishments*, NISTIR 6907, National Institute of Standards and Technology, Gaithersburg, Md., September 2002.

LABORATORY-LEVEL REVIEW

The mission of the Materials Science and Engineering Laboratory (MSEL) is to work with industry, standards bodies, universities, and other government laboratories to improve the nation's measurements and standards infrastructure for materials. MSEL is organized in four divisions: the Ceramics Division, Materials Reliability Division, Polymers Division, and Metallurgy Division. This chapter provides an assessment of the laboratory overall, and division-level reviews are provided in Chapter 13. MSEL also houses the NIST Center for Neutron Research, which is reviewed in a separate panel report at the end of Chapter 13. The MSEL organization is represented in Figure 6.1.

Major Observations

The panel presents the following major observations from its assessment of the Materials Science and Engineering Laboratory:

- The Materials Science and Engineering Laboratory continues in its tradition of undertaking and executing programs of high technical merit and strong relevance and effectiveness.
- The MSEL efforts in homeland security have been exemplary, and the laboratory should now consider extending those studies into a predictive mode.
- The panel hopes that control of overhead costs will be successful in stopping the erosion of technical staff and allow the laboratory to maintain its core competencies, its breadth of pursuits that attract high-quality scientists, and its ability to undertake new areas of research.
- MSEL has been very successful in leveraging its human resources through collaborations. The panel continues to support judicious use of collaborations, recognizing that many members of the technical staff are at optimum levels of collaborative efforts.

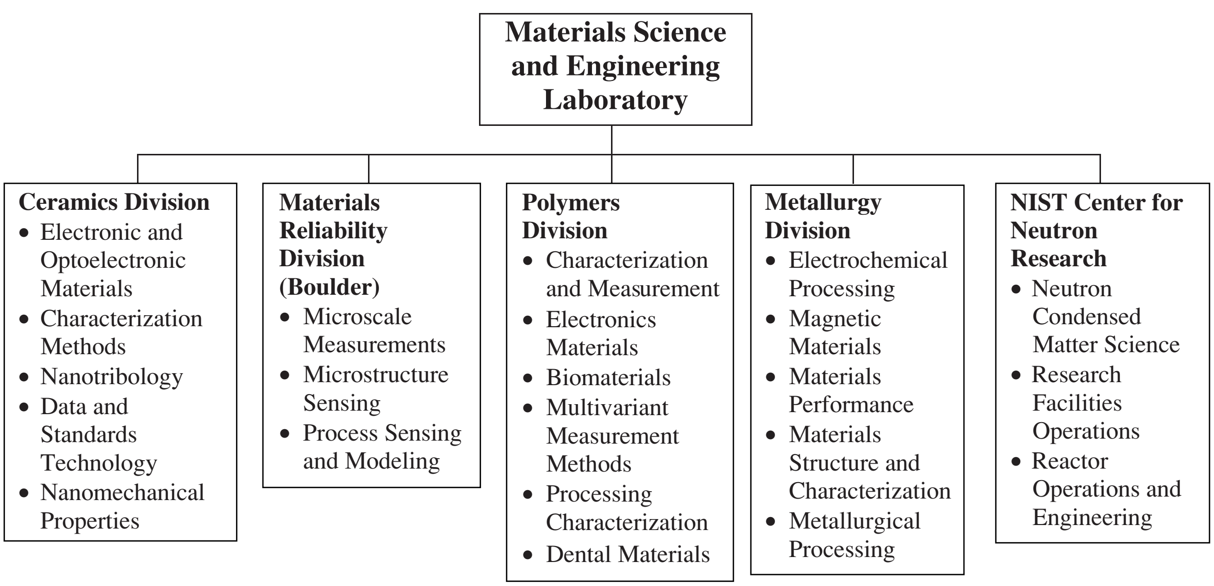

FIGURE 6.1 Organizational structure of the Materials Science and Engineering Laboratory. Groups are listed under each division and under the NIST Center for Neutron Research.

- Increased staff travel between Boulder and Gaithersburg has paid off in better cooperation between the two sites. Funding for such travel should be continued.
- The panel is particularly pleased with the effectiveness of efforts in the past year to enhance laboratory safety.
- The panel encourages the development of innovative methods for the maintenance, acquisition, and use of capital equipment.

Technical Merit

The technical quality of MSEL continues at a very high level, as evidenced by its quality contributions and impact on emerging science and technologies, the significant reliance on and use of its databases, practice guides, and Standard Reference Materials by national and international technical communities, and the recognition of its technical advances through numerous scientific awards and publications. The technical competence of staff members remains very high, and their projects often push the state of the art and its applications.

The level of accomplishment in the laboratory is quite high relative to that of similar organizations. The laboratory's output is generally excellent in terms of both quality and quantity. The panel continues to be particularly impressed with the outstanding accomplishments achieved by researchers through their effective use of available laboratory resources.

The panel noted in particular that the laboratory is making better use of collaborations both within and outside of NIST. This change has had a positive impact on programs, increasing the depth of expertise brought to technical problems and thus increasing the sophistication of the experiments and theory applied to their solutions.

Among the many MSEL programs with high technical merit and/or clear impact on national interests, the panel was struck particularly by the following contributions from each division:

- The Ceramics Division has provided leadership in maintaining and upgrading crystal structure databases and associated software tools accepted worldwide as universal standards.
- The Materials Reliability Division has made improvements in Charpy impact testing and standards that have wide customer support. Significant progress has been made toward setting an international standard for Charpy impact testing.
- The Metallurgy Division has had an impact through the lead-free solder program. This program addresses a worldwide environmental problem and provides the unique and enabling fundamental data that give the United States a competitive advantage in providing a solution.
- The Polymers Division has made significant advances in low-k dielectric thin-film nanoporous material characterization. This work supports the pressing needs for electronic materials and standard measurements.

Accomplishments such as these are of increased value to U.S. industry given that the level of materials research in industry has been scaled back in recent years.

Program Relevance and Effectiveness

In addition to the divisional highlights mentioned above, there are numerous programs in MSEL that support the mission and objectives of the laboratory and NIST. Following are examples of such programs and their relevance:

- *World Trade Center Program.* This program utilizes core competencies of the laboratory to build an understanding of the failure mechanisms in the World Trade Center's Twin Towers collapse. This understanding of the reaction of building materials to severe conditions and the development of specifications will be of great value in the domestic and foreign building industry.
- *Biomaterials.* The NIST biomaterials effort has the potential to occupy a unique and critically important niche at the interface between materials science and biology, and to be highly relevant in the development of metrology for both commercial and regulatory practices in biotechnology, pharmaceuticals, and medicine. While the effort is still in the early stages, it is well timed for the development of several initiatives, and the group's sensitivity toward maintaining integration with its customers is an important aspect of ensuring success. The panel is particularly impressed with the involvement of the National Institutes of Health (NIH) both as a resource and as an authoritative body in the biological field. The panel applauds the MSEL initiative to bring together the materials and biological sciences. The joint NIST/NIH postdoctoral program to be initiated this year will serve to strengthen this association.
- *Standard Reference Materials.* The laboratory's relevance and effectiveness continue to be demonstrated through its strong SRM program and the utility that these products find throughout industry.

The panel determined that the laboratory is enhancing its relevance and effectiveness through reliance on its strategic plan for the allocation of limited resources to a growing set of national needs. The laboratory is diligent in pursuing its Strategic Focus Areas (SFAs)—Nanotechnology, Health Care, Homeland Security, and Information Management—which provide a method of unifying individual projects toward a greater goal and providing avenues for new collaboration and growth. The panel commends the laboratory for maintaining a balance between these new focus areas and continued service to its historical constituency groups. The ongoing evaluation process, to prune programs that have ceased to be innovative while maintaining core competency, is important and must be continued. The management team is also encouraged to impart its enthusiasm for these focus areas to all levels of the organization. There is still some skepticism at the bench level concerning the lasting nature of the SFAs.

Laboratory Resources

Funding sources for the Materials Science and Engineering Laboratory are shown in Table 6.1. In January 2003, staffing for the laboratory included 169 full-time permanent positions, of which 139 were for technical professionals. There were also 55 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Appropriations for NIST are up about 6 percent this year, but because of required salary increases this gain once again essentially translates into a flat budget, and the panel is concerned that it could cause a possible loss of staff. At this point MSEL has the particular expertise that could contribute to the established NIST SFAs such as Homeland Security (nondestructive evaluation of infrastructure), Health Care (tissue engineering), and Nanotechnology. However, because of the steady decline in the number of MSEL staff the laboratory may be unable to step up to these challenges and opportunities. The panel is encouraged to see that the trend toward loss of technical staff is diminishing as a result of the effective control of overhead costs.

The laboratory management must remain particularly vigilant in maintaining the expertise and equipment necessary to respond to important opportunities that can contribute to national goals. The panel strongly encourages a systematic approach to the write-off of obsolete equipment and the devel-

TABLE 6.1 Sources of Funding for the Materials Science and Engineering Laboratory (in millions of dollars), FY 2000 to FY 2003

Source of Funding	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (actual)	Fiscal Year 2003 (July 2003 estimate)
NIST-STRS, excluding Competence	30.1	31.3	35.6	38.5
Competence	0.1	0.4	1.3	1.1
ATP	2.7	2.6	2.7	2.4
Measurement Services (SRM production)	0.7	1.0	1.3	1.1
OA/NFG/CRADA	3.9	2.8	3.5	4.5
Other Reimbursable	0.6	0.7	0.8	0.8
Total[a]	38.1	38.7	45.2	48.4
Full-time permanent staff (total)[b,c]	178	163	162	169

NOTE: Funding for the NIST Measurement and Standards Laboratories comes from a variety of sources. The laboratories receive appropriations from Congress, known as Scientific and Technical Research and Services (STRS) funding. Competence funding also comes from congressional appropriations but is allocated by the NIST director's office in multiyear grants for projects that advance NIST's capabilities in new and emerging areas of measurement science. Advanced Technology Program (ATP) funding reflects support from NIST's ATP for work done at the NIST laboratories in collaboration with or in support of ATP projects. Funding to support production of Standard Reference Materials (SRMs) is tied to the use of such products and is classified as "Measurement Services." NIST laboratories also receive funding through grants or contracts from other [government] agencies (OA), from nonfederal government (NFG) agencies, and from industry in the form of cooperative research and development agreements (CRADAs). All other laboratory funding, including that for Calibration Services, is grouped under "Other Reimbursable."

[a]The funding for the NIST Center for Neutron Research (NCNR) is excluded from these totals. Information about the center's funding is available in the section of this chapter titled "Review of the NIST Center for Neutron Research," which contains the panel review of that facility.

[b]NCNR personnel are excluded from these totals. Information about the center's personnel is available in the section titled "Review of the NIST Center for Neutron Research" in Chapter 13.

[c]The number of full-time permanent staff is as of January of that fiscal year.

opment of innovative methods for the maintenance, acquisition, and use of capital equipment. An example may be that of soliciting and accepting state-of-the-art characterization tools from the manufacturers of such equipment. While NIST cannot endorse such equipment, the presence in NIST publications of footnotes describing the equipment used for experimentation may be an incentive for companies to donate or significantly reduce the cost of equipment.

Many important MSEL staff members are approaching retirement eligibility; before these individuals leave, it is crucial to have mentoring and training of new staff in the skills of retiring staff. Junior staff at the laboratory report that the presence of a strong cohort of colleagues is a major reason that they have chosen to work at NIST. If the number of senior personnel continues to decrease, this sense of being surrounded by the best colleagues will diminish, and the laboratory may find it difficult to attract and retain researchers with the skills needed to address important emerging areas of science relevant to NIST's overall priorities. As in last year's report, the panel strongly recommends that management strategy set a priority on ensuring a viable transfer of expertise in its key areas.

MSEL has some very good examples of leveraging its human resources through collaborations. Its programs in biomaterials, health care, and homeland security are particularly good examples. These programs involve collaborations with other laboratories at NIST and with external researchers at other government agencies and in industry. The programs consequently have the potential for far greater accomplishment and impact than if MSEL had attempted to enter the areas on its own. The panel encourages MSEL to continue to use collaborations judiciously to extend the impact of its programs, and it urges MSEL to look for additional areas in which its resources might be so leveraged.

MSEL has a unique management challenge because a portion of its staff resides in Boulder, Colorado. The laboratory has improved coordination between these sites by imposing few budgetary barriers to team-building travel between the two sites. Not only has this approach improved collaboration between the Boulder and Gaithersburg staff, but it also allows the laboratory to make much better use of the skills resident in Boulder. Some concerns remain within the Boulder community about visibility and recognition by the Gaithersburg management team, and these concerns warrant attention, although the recent visit by the NIST laboratory director was very well received. The management team is also encouraged to find ways to increase the bench scientists' sense of personal responsibility and ownership of the laboratory activities and to encourage them to suggest solutions to organizational as well as technical problems.

The panel applauds the decision to hold the 2003 MSEL review meeting in Boulder. This gave the full panel an opportunity to see the researchers and facilities in the Materials Reliability Division. The staff of this division is anxious about the future, with the announced pending retirement of the division chief. The panel noted that the apparent NIST policy or tradition that prevents naming a successor before a position is vacant prevents real succession planning and leads to lapses of management continuity and excessive anxiety in the technical staff.

This year has seen efforts to establish closer collaborations between MSEL and EEEL at Boulder. The Materials Reliability Division has established linkages to the Optoelectronics, Radio-Frequency Technology, and Magnetic Technology Divisions of EEEL, which in turn is establishing coordinated efforts with the Ceramics and the Metallurgy Divisions in Gaithersburg. These collaborations have established broad-based units of expertise that will be well poised for the development of new initiatives within the NIST mission.

Facilities for the Boulder researchers have improved somewhat but are still problematic and below standards for laboratory space of this sort. The panel is pleased to hear that some funding has finally been appropriated to improve the Boulder buildings and hopes that these or other funds will allow for repairs to prevent the roof leakages that have plagued one of the buildings for a long period of time.

Laboratory Responsiveness

The panel found excellent MSEL responsiveness to its previous report.[2] In fact, last year the panel's report also mentioned the excellent responsiveness of laboratory managers to the panel's recommendations and suggestions. For example, senior managers have held sessions concerning nanotechnology and homeland security to identify methods for support of the NIST SFAs in these areas, offsite meetings have been held between technical management and selected staff members to improve communication with respect to the laboratory's priorities, and in almost all cases where specific program focus and direction had been questioned by the panel, the laboratory reexamined its programs and either adjusted

[2]National Research Council, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2002*, National Academy Press, Washington, D.C., 2002.

the focus or terminated the program. The laboratory has also taken a proactive approach to safety in its laboratory facilities, as evidenced by the installation of new safety equipment and the establishment of a staff performance plan to encourage routine safety practices. The panel applauds the laboratory on this responsiveness. Continued attention is needed to more general concerns, such as the potential for subcritical staffing of important programs and the maintenance of key areas of investigation to secure the laboratory's role in the strategic mission of NIST.

Similarly, reviewers found the divisions to be very responsive to their previous reports. Responsiveness is discussed in the division reports in Chapter 13, but a few examples are as follows:

- The Polymers Division has phased out some programs in order to focus on emerging technologies.
- The Materials Reliability Division has consolidated programs around core competencies and formed centers of excellence.
- The Ceramics Division has made recommended strategic hires in nanotribology.
- The Metallurgy Division has improved its nanomagnetodynamics program.

The laboratory is encouraged to take a greater role in assessing future industry and national needs and in identifying the fundamental scientific questions underlying such needs.

7

Building and Fire Research Laboratory

PANEL MEMBERS

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Donald B. Bivens, DuPont Fluorochemicals
Randy R. Bruegman, Clackamas County Fire District #1, Oregon
Tsu-Wei Chou, University of Delaware
Joseph P. Colaco, CBM Engineers, Inc.
Martin Fischer, Stanford University
Kristin H. Heinemeier, Brooks Energy and Sustainability Laboratory
Robert J. Hitchcock, Lawrence Berkeley National Laboratory
Susan D. Landry, Albemarle Corporation
John Mitchell, University of Wisconsin
Adel F. Sarofim, University of Utah
Jim W. Sealy, Architect/Building Code Consultant, Dallas, Texas
William K. Secre, Master Builders, Inc.
Frieder Seible, University of California, San Diego
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Elaine M. Yorkgitis, Automotive Division/3M

Submitted for the panel by its Chair, Robert A. Altenkirch, and its Vice Chair, Ross B. Corotis, this assessment of the fiscal year 2003 activities of the Building and Fire Research Laboratory is based on site visits by individual panel members, a formal meeting of the panel on February 27-28, 2003, in Gaithersburg, Maryland, and materials provided by the laboratory.

LABORATORY-LEVEL REVIEW

The mission of the Building and Fire Research Laboratory (BFRL) is to meet the measurement and standards needs of the building and fire safety communities. The BFRL is organized in four divisions: the Materials and Construction Research Division, Building Environment Division, Fire Research Division, and Office of Applied Economics (see Figure 7.1). The first three divisions are responsible for BFRL's main technical thrusts: advanced construction technology, high-performance construction materials, enhanced building performance, and fire loss reduction. Technical work is also under way in the Office of Applied Economics (OAE). In addition, BFRL performs activities in the area of codes and standards. This chapter provides an assessment of the laboratory overall, and the units and activities are discussed in detail in the division reviews in Chapter 14.

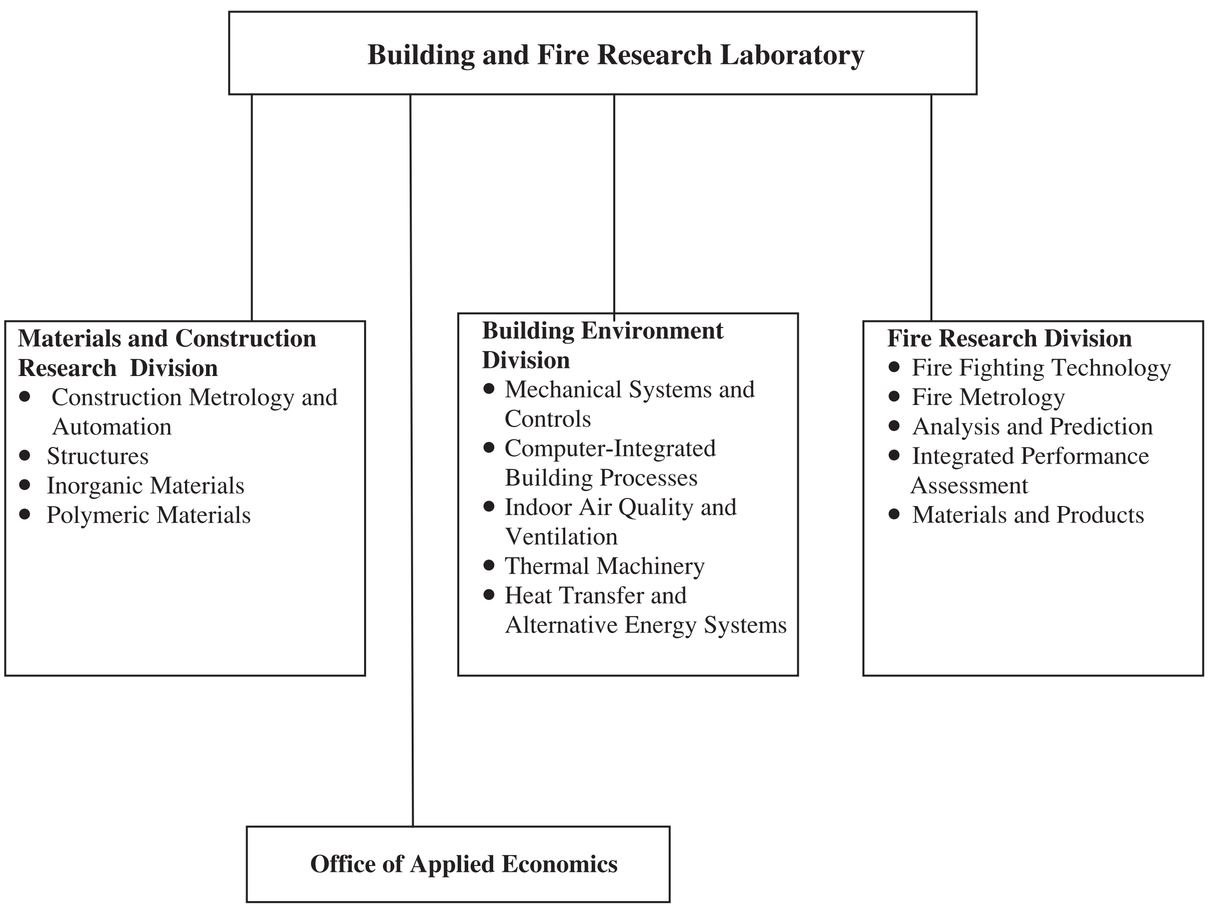

FIGURE 7.1 Organizational structure of the Building and Fire Research Laboratory. Listed under each division are its groups.

Major Observations

The panel presents the following major observations from its assessment of the Building and Fire Research Laboratory:

- The panel continues to be impressed by the high quality of scientific and technical work produced in the Building and Fire Research Laboratory. Commendable efforts are made to reach out to a broad variety of laboratory customers, ranging from large construction companies to local firefighting units, from code makers to academic researchers, and from standards committees to the public. BFRL staff take advantage of the special tools and expertise that exist in the laboratory to provide their customers with unbiased, technically excellent work focused on the measurement and testing needed to improve the quality of materials and technologies.
- Overall, staff morale at BFRL is good. Staff show excitement at and derive satisfaction from the opportunity to devote their talents to the challenges and opportunities associated with homeland security issues, which are many and require careful planning to achieve the effective balance of longer-term basic research and timely applications of results.
- The reorganizations in late 2000 and in 2002 within BFRL are proceeding well. Peaceful coexistence has been readily achieved, and the time is ripe for seeking and taking advantage of opportunities for synergy.
- Combining two formerly separate divisions into the Materials and Construction Research Division has produced an opportunity for beneficial synergistic effects; increased interactions across the groups could lead to significant future successes.
- The National Construction Safety Team Act presents a tremendous opportunity for BFRL. The laboratory still has to define a strategy for deploying resources to an investigation and, once completed, for disseminating the results. In addition, findings may have an impact on future research and codes and standards application; a plan needs to be developed to ensure that the results of the investigation are applied appropriately in industry.
- The laboratory has taken early steps toward the development of a strategic plan and of performance metrics. Next steps should include the specification of time lines, milestones, and interdependencies.
- BFRL's existing expertise and programs have placed it in an excellent position to make many positive contributions to the nation's homeland security efforts. The panel is very supportive of BFRL's ongoing and planned activities but cautions that it is vital for the laboratory to maintain a balance between short-term investigative work and long-term programs aimed at developing research and applications that are broadly relevant. The laboratory must take care to preserve its strong relationships with existing customers, in part by demonstrating how the homeland security work will help the laboratory continue to meet those customers' needs. Also, the laboratory will face new and complex challenges in the personnel and project management areas associated with a large, multiorganization project, and new skills and people will be needed for this task. Specifically, there has to be a clear definition of the involvement of all relevant groups in the World Trade Center (WTC) investigation. The WTC investigation plan has been fleshed out to address specific objectives encompassing multiorganizational projects. However, organizational and work-related plans need to be defined by a detailed work breakdown structure, milestones, and schedules, so that the project can be effectively managed and so that its status can be clearly communicated. Such a large effort merits a dedicated and skilled project management staff. Plans should include strategies for taking advantage of any opportunities presented to expand the laboratory's expertise and relevance.

• Structural fire testing is both an important element of homeland security work and an appropriate long-term programmatic growth area for BFRL and its customers. The laboratory should encourage pursuit of the construction of a state-of-the-art facility for the fire testing of structures under load as part of the homeland security effort and should make a commitment to sustaining a structural fire research program over the long term. This is an area in which BFRL is uniquely positioned to do high-quality, high-impact work.

• For BFRL to have an impact on the construction industry (and ultimately the public), the laboratory's technical knowledge and results must be utilized in codes and standards and adopted as the industry's normal practices. High-quality and important test and standards work is already occurring in BFRL, but coordination across projects at the laboratory level is needed; this coordination should include monitoring the allocation of staff expertise and time to accomplish the development, adoption, and use of regulations.

• BFRL staff remain conflicted and confused about issues pertaining to intellectual property procedures and policies at NIST. Management should communicate its philosophy about when patents and copyrights should be pursued, the personal and laboratory costs and benefits associated with such pursuits, the level of support that management is willing to provide for such efforts, and clear procedures for their pursuit.

Technical Merit

The panel continues to be impressed by the high quality of scientific and technical work produced in BFRL. Many projects exemplify the ways in which laboratory staff use the expertise, instrumentation, and simulation and modeling tools that are often unique to BFRL to take advantage of NIST's singular role as an unbiased voice focused on measurement and testing to improve the quality of building technologies and materials. Examples of projects with high technical quality and merit are listed below.

• *Within the Materials and Construction Research Division:*

—The Inorganic Materials and the Polymeric Materials Groups develop test methods and predictive tools for next-generation construction materials such as high-performance concrete, coatings, and sealants. Each works over size scales from the nanometer level to the macroscopic level and seeks out, develops, and uses state-of-the-art analytical and measurement tools. The Inorganic Materials Group is sophisticated in its use of modeling, databases, and other computer-based tools. The Polymeric Materials Group is highly proactive in developing laboratory automation and accelerated durability testing.

—The strength of the materials groups is their work in establishing the fundamental bases of the durability of building materials. Staff have expertise in the broad range of disciplines that constitute materials science and engineering: chemistry, physics, engineering, environmental health and safety, and economics. The umbrella project of the Inorganic Materials Group, referred to as the HYPERCON program, recently completed the second year of a 3-year consortium aimed at developing and validating its Virtual Cement and Concrete Testing Laboratory (VCCTL). The program continues to make strides in measuring, understanding, and predicting the performance of high-performance concrete.

—The division is providing significant technical contributions to the laboratory's homeland security work, including efforts in the investigation of the World Trade Center's Twin Towers collapse, structural fire protection, and building vulnerability reduction.

• *Within the Building Environment Division:*

—The Indoor Air Quality and Ventilation Group has conducted significant basic research on air and contaminant flow in conventional and hybrid ventilation systems and has disseminated this information to the technical community. Members of the group have been leaders in the development of standards and design tools for ventilation and indoor air quality. They are applying their skills to the evaluation of the effect that control strategies have on energy use and indoor air quality in both residential and commercial buildings.

—The Heat Transfer and Alternative Energy Systems Group is conducting an alternative-energy project with the goal of developing measurement techniques, testing methods, rating methodologies, and simulation methods for photovoltaic systems. This is a solid program that is providing important baseline data on photovoltaic systems.

- *Within the Fire Research Division:*

—A core of the division's modeling efforts is the development, application, and distribution of the Fire Dynamics Simulator (FDS). The FDS software incorporates advanced turbulence models (large eddy simulation), gas radiation, and scientific visualization in an efficient computational scheme that is able to run on desktop computers. The capabilities of the model have been enhanced in the recently released Version 3.0 of FDS by the incorporation of absorption and scattering by droplet sprays, multigrid capability, a mixture fraction combustion model, and gas radiation. Work is continuing on further refinements of the model, to include parallelization, soot radiation, improved subgrid turbulence models, and improved heat and mass transfer at surface boundaries.

—The Materials and Products Group has performed high-quality and very relevant work on the flammability of residential mattresses. The group has worked with the mattress industry over the past 4 years to develop a flammability test method that reflects real-world bed-fire behavior.

- *Within the Office of Applied Economics:*

—OAE's activities identify relevant theoretical advances in applied economics and develop the means to apply them to the design and construction industry. OAE is recognized as a world leader in the application of these theories to the built environment.

—OAE is particularly strong in the area of enhanced building performance and the development of tools to aid in decision making for the building and fire safety communities. OAE's software-based systems have been established as the standard in such areas as life-cycle costing and energy efficiency. OAE has established the cost/time trade-offs for a number of building and fire systems, including systems to support building for environmental and economic sustainability, bridge life-cycle costing, fire safety gear selection, and a decision support system for the Department of Housing and Urban Development's program for advanced technology for housing.

Organizational Changes

Organizationally, BFRL is evolving through a series of changes. In late 2000, the Fire Research Division was formed from the combination of two divisions. The panel is pleased to report this year that the transition continues to be going very well. Increased collaboration and good communications within the division were observed. The division is embracing stakeholder perspectives, broadening its outreach, clarifying its goals and objectives, and stabilizing its financial situation.

Last year, BFRL also merged two divisions, Structures and Building Materials, into the Materials and Construction Research Division. These divisions focus on somewhat different areas, but combining their expertise will give the laboratory an opportunity to lay the groundwork for a future in which materials are engineered to meet specific long-term structural performance requirements. The panel has observed that these different cultures are coexisting peacefully but separately, and it continues to urge a focus on areas of potential synergy.

Program Relevance and Effectiveness

As mentioned above, laboratory staff have had increasing success building relationships with their customers in a wide variety of industries and communities. The examples below illustrate activities that are relevant and effectively planned and/or performed:

- *Within the Materials and Construction Research Division:*

—Both the Inorganic Materials and the Polymeric Materials Groups are well connected in industry and relatively well connected in academia. Both groups provide technical support for improving standards and criteria for evaluation, selection, and use of their respective materials and, additionally, support the needs of various federal agencies in addressing the construction and infrastructure needs of the nation.

—The HYPERCON program of the Inorganic Materials Group continues to effectively support and generate interest in the construction community, as represented by materials suppliers to that industry. Over the past year, VCCTL has been accessed via the Internet by about 9,000 users per month, from more than 80 countries. It is clearly seen as a valuable resource in the computational and experimental materials science of concrete and its constituents.

—As the VCCTL consortium completes the last of its 3 years, the panel is very interested in seeing the development of a plan to take the tools of VCCTL not only to the 4,000 ready-mix concrete producers of the United States as well as those of other nations, but also to construction companies and concrete contractors, building designers including engineers and architects, and prospective owners of concrete-intensive structures. While VCCTL has been designed to be used as one large modeling package, some individual components of VCCTL may prove to be of greater use than others to certain entities, and they should be packaged in such a way that their effective stand-alone use is possible. The plan that the panel recommends should additionally provide a clear means for application of VCCTL and its components to code and standards development.

—With its strong consortium support, the Polymeric Materials Group has both firm financial backing and a rich supply of industrial input on what is of most relevance to manufacturers of coatings, sealants, and other polymeric building materials.

—The division's work relevant to homeland security activities includes efforts in support of the investigation of the World Trade Center's Twin Towers collapse.

- *Within the Building Environment Division:*

—The research projects of the Indoor Air Quality and Ventilation Group represent an important component of the effort in the area of healthy and sustainable buildings. The current projects are a natural outgrowth of the need to understand the role of airflow in buildings on energy use and on occupant health and comfort. The projects continue to evolve to meet changing national priorities. The group is recognized nationally for its expertise and is working with other government agencies on problems of national interest. One of the key areas is that of airflow and pollutant model development. The group has developed a number of analytical methods that are widely used in the research, development, and design communities.

—The Heat Transfer and Alternative Energy Systems Group is conducting an alternative energy project with the goal of developing measurement techniques, rating methodologies, and simulation methods for stationary fuel cells. The proposed testing methodology describes in detail the tests that will be performed and how the basic characteristics will be determined. This appears to be a solid plan that will yield results that will become increasingly important as the fuel cell industry develops.

—The Mechanical Systems and Controls Group has led the buildings industry in the development of the Building Automation and Control Network (BACnet®) protocol, which enables the use of and communication between different types of control systems in commercial buildings. A second important building-related project of the group is that on automated commissioning and fault detection and diagnostics (FDD) of heating, ventilation, and air-conditioning (HVAC) equipment.

- *Within the Fire Research Division:*

—Experimental and theoretical tools are being applied to the goals of reducing fire loss and improving firefighter protection. Progress is being made on the search for improved fire-resistant materials.

—The Fire Dynamics Simulator has been widely used for fire reconstruction, for providing educational tools for firefighters and the public, and for guiding the research program through the design of experiments.

—The Fire Research Division (FRD) has a significant role in NIST's World Trade Center follow-up and homeland security work. The staff is energized by the challenges and opportunities posed by these efforts, and they need to continue to position the laboratory to ensure their future role in this area. The division, and in particular its Fire Fighting Technology Group, have done an excellent job at outreach in providing firefighter support.

—One area in which FRD is currently participating, but on which it should focus more, is the area of codes and standards. This could be facilitated either by forming a subgroup that has more staff or by creating a division that concentrates on codes and standards. This group could provide the staff support for the large number of FRD personnel who now serve and often chair standards committees.

—One specific problem that FRD appears to have concerns the National Environmental Policy Act (NEPA). In order for FRD to gather data with a planned fire test, NIST must go through a formal process of obtaining permits. This process is expensive and time-consuming. This NEPA permitting process appears to be a hindrance to the FRD's gathering of data by means of this avenue of fieldwork.

- *Within the Office of Applied Economics:*

—The projects in OAE focus specifically on meeting the requirements of the building and fire safety community, particularly through the assessment of the adequacy of economic resources to accomplish this community's objectives within a set of available choices. Many of the projects within OAE are funded from external sources and respond directly to the needs of the community, thereby ensuring direct relevance to the community.

—OAE is active in all of the BFRL mission goals and in the overall NIST strategic objectives. It is particularly strong in the area of enhanced building performance. In addition, OAE develops critical tools to aid in decision making for the building and fire safety communities. Its collaboration with the other BFRL divisions (Materials and Construction Research, Building Environment, and Fire Research) further leverages the expertise and impact of the BFRL as a whole.

—OAE's recent contributions of Web-enabled decision support tools allow an expanding population of users throughout the United States and internationally to understand and utilize economic methods to assess different technological alternatives. OAE currently provides Internet access to most of its software programs.

- *Within activities related to BFRL's standards and codes work:*

—The audience for BFRL's work in standards and codes includes the manufacturers of relevant products and regulators in the United States and in other countries. However, for BFRL's work to influence standards and codes, staff must take into account regulators' need for timely information.

—BFRL has a key role in the follow-up after major building failures and fires. This role includes supporting the analysis of methods of exiting buildings and facilities in real or perceived emergencies.

Laboratory Resources

Funding sources for the Building and Fire Research Laboratory are shown in Table 7.1.

The panel's concerns about funding, highlighted in the 2002 report, are somewhat lessened this year. However, the panel is concerned about staffing and hiring (there is a need, emphasized by BFRL staff during skip-level interviews (sessions in which management does not participate), for a greater number of technicians, and questions remain about how best to staff the homeland security activities). In addition, the panel observed space restrictions that may potentially inhibit the technical quality of work, and there is a need for a clear capital investment plan.

As a result of congressionally allocated funding related to homeland security, BFRL has begun to receive significant funding, expected to continue in the near term. The panel remains pleased to see that BFRL has the support of NIST management and Department of Commerce management as it goes through the budget process and prepares to begin its homeland security-related program. While initial steps have been good and appropriate, the laboratory must be cautious going forward to make careful decisions about such reprogramming—about whether a temporary or a permanent shift in focus is occurring—and to clearly communicate the rationale and final outcome to staff. This is one element of the broader question of how BFRL will determine and maintain a balance between new homeland

TABLE 7.1 Sources of Funding for the Building and Fire Research Laboratory (in millions of dollars), FY 2000 to FY 2003

Source of Funding	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (actual)	Fiscal Year 2003 (July 2003 estimate)
NIST-STRS, excluding Competence	16.6	18.8	26.6	27.5
Competence	0.2	0.2	0.0	0.0
STRS, nonbase	1.5	1.9	—	—
ATP	0.7	1.1	1.4	1.2
MEP	0.1	0.0	0.0	0.0
OA/NFG/CRADA	11.2	9.1	11.7	14.4
Other Reimbursable	0.2	0.1	0.3	0.2
STRSWTC R&D	—	—	—	—
WTC Investigation	—	—	—	—
Total	30.5	31.2	40.0	43.3
Full-time permanent staff (total)[a]	157	150	156	155

NOTE: Funding for the NIST Measurement and Standards Laboratories comes from a variety of sources. The laboratories receive appropriations from Congress, known as Scientific and Technical Research and Services (STRS) funding. Competence funding also comes from NIST's congressional appropriations but is allocated by the NIST director's office in multiyear grants for projects that advance NIST's capabilities in new and emerging areas of measurement science. Advanced Technology Program (ATP) funding reflects support from NIST's ATP for work done at the NIST laboratories in collaboration with or in support of ATP projects. Manufacturing Extension Partnership (MEP) funding reflects support from NIST's MEP for work related to NIST's support of the MEP centers throughout the United States. NIST laboratories also receive funding through grants or contracts from other [government] agencies (OA), from nonfederal government (NFG) agencies, and from industry in the form of cooperative research and development agreements (CRADAs).

[a]The number of full-time permanent staff is as of January of that fiscal year.

security work and existing projects, including contracts with other government agencies. The panel continues to note that the refinement of a strategic plan may help define criteria that BFRL can apply to maintaining a proper balance of work. A strategic plan will need a core commitment of internal funds or stable external funds to support a long-term vision.

In January 2003, staffing for the BFRL included 155 full-time permanent positions, of which 132 were for technical professionals. There were also 38 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers. An understanding of the expectations for long-term staffing levels should allow the laboratory to focus on replacement of talent and on smooth programmatic transitions when staff retire or depart. The massive, planned homeland security effort should result in a large number of new people coming, probably temporarily, to work at NIST, and this may be an opportunity for BFRL to consider what type of new personnel it wishes to recruit when permanent slots open up and to see many potential candidates in action.

Another potential opportunity in the homeland security effort is the development of a large-scale, state-of-the-art, structural fire test facility. The laboratory's plans for homeland security activities do include work on the fire testing of structures under load, but the panel believes that the plan for this activity can be significantly expanded. Owing to the laboratory's strong expertise in both structural and fire research and to its existing Large Fire Research Facility, BFRL is in a unique position to build a robust, long-term program in this area and to utilize this kind of facility effectively. Homeland security funding could be used to initiate work on a state-of-the-art facility, but the laboratory must make a commitment to sustaining the facility and the program over the long term. In order to secure the funding for such a facility and to lay the groundwork for a vigorous and effective program in this area, the panel recommends that BFRL define its vision of what a state-of-the-art facility for large-scale structural fire testing should be and what the test objectives should be, and that it pursue a development, implementation, and maintenance strategy to secure funding and build and maintain the program.

Laboratory Responsiveness

The panel found the laboratory to be open and responsive to recommendations made in past assessment reports.

8

Information Technology Laboratory

PANEL MEMBERS

Albert M. Erisman, Institute for Business, Technology, and Ethics, *Chair*
C. William Gear, NEC Research Institute, Inc. (retired), *Vice Chair*
Michael Angelo, Hewlett-Packard Corporation
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John Boot, Motorola Corporation
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James A. Calvin, Texas A&M University
Susan T. Dumais, Microsoft Research
John R. Gilbert, Xerox Palo Alto Research Center
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Mary Ellen Zurko, IBM Software Group

Submitted for the panel by its Chair, Albert M. Erisman, and its Vice Chair, C. William Gear, this assessment of the fiscal year 2003 activities of the Information Technology Laboratory is based on visits by members of the panel to the ITL divisions, a site visit by the panel on March 24-25, 2003, in Gaithersburg, Maryland, and documents provided by the laboratory.[1]

[1]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Information Technology Laboratory Technical Accomplishments 2002*, NISTSP 6909, National Institute of Standards and Technology, Gaithersburg, Md., November 2002; U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Report to the ITL Assessment Panel*, National Institute of Standards and Technology, Gaithersburg, Md., March 2003; U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Information Technology Laboratory Publications 2002*, National Institute of Standards and Technology, Gaithersburg, Md., March 2003.

LABORATORY-LEVEL REVIEW

The mission of the Information Technology Laboratory (ITL) is to develop and promote measurement, standards, and technology for information technology (IT) to enhance productivity, facilitate trade, and improve the quality of life. To carry out this mission, the laboratory is organized in seven divisions (see Figure 8.1): Mathematical and Computational Sciences, Advanced Networking Technologies, Computer Security, Information Access, Convergent Information Systems, Software Diagnostics and Conformance Testing, and Statistical Engineering. This chapter presents an assessment of the laboratory overall, discussing some highlights and overarching issues. A selection of the activities of these units is commented on at length in the division reviews in Chapter 15.

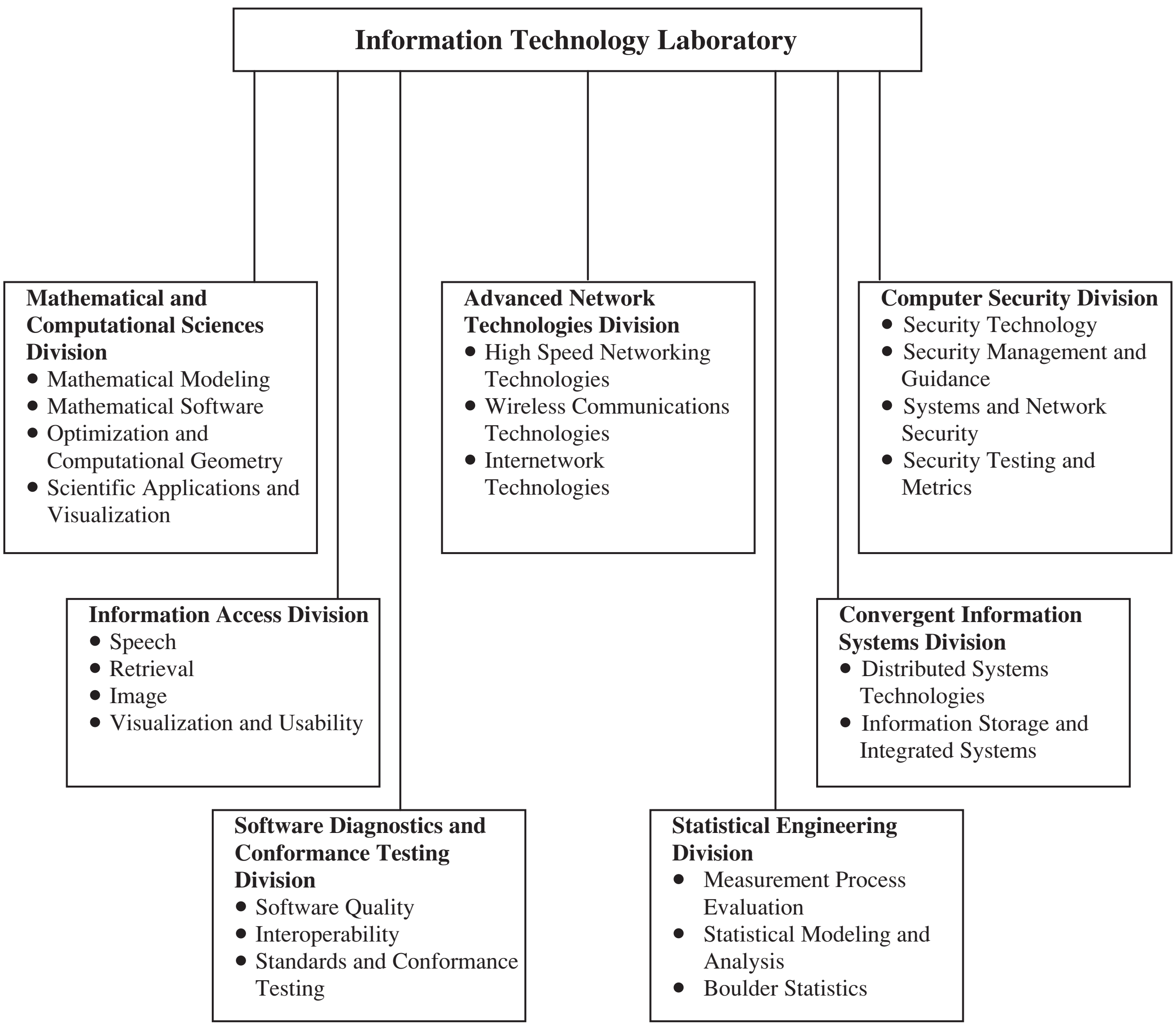

FIGURE 8.1 Organizational structure of the Information Technology Laboratory. Listed under each division are its groups.

Major Observations

The panel presents the following major observations from its assessment of the Information Technology Laboratory:

- The overall technical quality and the merit, relevance, and effectiveness of the Information Technology Laboratory's programs and staff remain strong. Examples of high-quality, meritorious, relevant, and effective projects are many and exist in all divisions.
- There is ample evidence of outstanding work in leveraging technology ideas across customer areas for industry, academia, government, and within NIST.
- Collaboration across ITL divisions and between ITL and other NIST laboratories is increasing, and projects increasingly are demanding multidisciplinary team approaches. In the current flat or declining funding environment, such projects (e.g., in pervasive computing) demand especially careful management.
- Progress has been made in terminating good but less important projects. This skill needs to become even more widespread as demands for work expand without commensurate expansion of resources.
- It is important that ITL staff take into account not only the scientific and technical aspects of projects but also their psychosocial context, so that the laboratory avoids the mistake of endorsing products that cause psychosocial problems (e.g., lack of integrity leading to users' mistrust). A particularly important new project that raises this concern involves electronic voting.
- The transfer of IT support functions to the Office of the Chief Information Officer (CIO), which is separate from ITL, holds promise for garnering NIST-wide recognition of the importance of standardized, reliable IT service. Both the CIO office and the ITL should maintain effective, cooperative communication and activity to ensure the application of IT technology and practice appropriate to NIST.
- ITL has worked hard and effectively to develop metrics for its performance. ITL should work with customers—and the panel should assist—to further develop means of assessing the effectiveness of ITL projects and products.
- The panel commends ITL for its careful work with consortia, properly participating in the standards activity while avoiding the endorsement of vendor-specific products. The panel urges ITL to continue its efforts to refine and implement its policy to help divisions decide when participation in closed consortia is appropriate and to consider how NIST can encourage industry to utilize open, or at least inclusive, approaches to standards development.
- Skip-level meetings with the panel and employee surveys confirm that morale within ITL is high: ITL members enjoy their work, take pride in its quality and effectiveness, and appreciate the atmosphere of mutual respect. They expressed some confusion about the plans to fill the director's position; about the import of Office of Management and Budget Circular A-76, which establishes federal policy for the competition of commercial activities; and about impacts of outsourcing—explanation by management would allay this confusion.
- The housing of part of the ITL staff at NIST North inhibits, to some extent, the ability of staff to collaborate (especially junior staff who have not established a collaborative network). It is time for ITL to apply its knowledge for the benefit of its own staff by providing effective IT workarounds such as electronic collaboration technologies to ameliorate this problem. Nevertheless, NIST should continue to work toward more consolidated facilities because of the power of face-to-face activity.

Technical Merit

The technical merit of the work in ITL remains strong. As part of its onsite reviews, the panel had the opportunity to visit each of the divisions for a variety of presentations and reviews related to the projects currently under way. On the basis of its sampling of ITL projects, the panel has been consistently impressed with the technical quality of the work undertaken. Many examples of programs with especially strong technical merit are highlighted in the division reviews in Chapter 15 and include the following:

- *Within the Mathematical and Computational Sciences Division:*

—The work on solidification modeling is a long-running, collaborative effort with the Materials Science and Engineering Laboratory that has yielded significant advances in modeling capability.

—The Digital Library of Mathematical Functions project is ambitious, excellently performed, and important.

- *Within the Advanced Networking Technologies Division:*

—The Internet Telephony project has continued its considerable progress, with a focus on call signaling protocols; this project remains a model for industrial collaboration and balances the maintenance of existing software tools with the need to advance the division's research agenda.

—The first-responders project is a promising and ambitious exploratory project that is well matched with the division's research competencies.

- *Within the Computer Security Division:*

—The Cryptographic Module Validation program is an important and well-conducted effort that continues to uncover and correct a large number of flaws in algorithm implementation and documentation, providing a common definition of "assurance" for users of those modules.

—The system administration guidance for the Windows 2000 Professional project can have an impact on Microsoft's own secure configuration development efforts; can establish a configuration with known security properties for use by system administrators, application developers, and auditors; and represents exemplary cooperation with industry (Microsoft).

- *Within the Information Access Division:*

—The efforts in support of the Text Retrieval Conference (TREC) continue to represent leadership and coordination of research, with a focus on key common and relevant problems in the field of information retrieval.

—Work in the area of evaluation methodologies and standards to support usability and accessibility is in good alignment with the division's strengths and represents good progress in this high-impact area.

- *Within the Software Diagnostics and Conformance Testing Division:*

—Due to its outstanding track record in working successfully with industry and providing technical leadership and unbiased feedback, the Standards and Conformance Testing Group has expanded its conformance testing beyond extensible markup language (XML) to include related technologies.

—Work in the area of health care information systems is well conceived, promising, and important.

- *Within the Statistical Engineering Division:*

—The division continues to be the leading presence in the area of key statistical comparisons, developing new and effective methods to help determine the degree of equivalence among measurement standards of different nations.

—The division provides important statistical support to the scientific research conducted across all NIST laboratories, which ranges from short-term activities to extensive collaborations requiring the generation of new statistical methodology.

- *Within the Convergent Information Systems Division:*

—The work on digital preservation (content storage) represents effective collaboration with industry, government, and universities to develop metrology methods, technologies, and standards that support efforts by the data storage industry and government efforts in digital preservation, a national issue.

- The quantum communication testbed is an enabler of important first steps in exploring the viability of cryptographic key distribution as a practical technology for commercial and defense applications. The testbed is also an enabler of test, calibration, and development efforts in the area of quantum communication.
- *Cross-divisional projects:*

—Several cross-divisional efforts are being applied to the field of biometrics. The Information Access Division is performing good work in the accumulation and testing of large fingerprint and face test sets for the purpose of evaluating verification and identification rates. With the large databases, its Image Group is expected to be able to determine statistics and also to evaluate operational issues that will occur with very high volumes of enrollment and verification (for example, in border and visa security). There is new and productive cooperation between the Convergent Information Systems Division (which has been performing critical work on the development of standards, prototypes, and test methods and data for multimodal biometrics technologies) and the Information Access Division (which is expanding its role beyond support of government and law enforcement). Whereas interest and support came mainly from the FBI in the past, a wider range of government agencies are now supporting and making reference to NIST recommendations on biometrics.

—Pervasive computing efforts are also being conducted effectively by the Information Access Division and by the Advanced Networking Technologies Division, which is addressing wireless networking and standards and performing analysis of the resource discovery protocols being developed for ubiquitous computing systems. An example of cross-laboratory interaction is the use of the Smart Space testbed, part of the pervasive computing infrastructure, for the Single Molecule Manipulation and Measurement project undertaken by NIST's Chemical Science and Technology Laboratory and the Physics Laboratory.

The panel also continues to see progress in the divisions on rational, well-justified decisions about what projects to start and conclude and when to do so.

The panel urges ITL to vigorously address two important issues that may help to improve the technical quality and merit of the laboratory's work:

1. The psychosocial factors related to electronic voting should be analyzed so that potential problems (e.g., issues pertaining to the verification of votes and related issues such as implications for trust in automated systems, amplified by private ownership of the voting system and related security concerns) are identified and so that NIST is not perceived as endorsing the use of a possibly problematic system.
2. The expanded interest in and support of NIST's biometrics work, as well as the importance of the timely development of biometrics for homeland security, encourage the development of a clear plan for integrating the efforts across divisions so that resources are applied effectively and priorities are addressed, and for tapping relevant divisional expertise. For example, it will be important to expand the

involvement of the Computer Security Division in this field, and the Statistical Engineering Division could make substantial contributions with appropriate experimental design and modeling support in many experimental and simulation contexts.

Program Relevance and Effectiveness

ITL has a very broad range of customers, including scientists and engineers, from industry, academia, and government and from within NIST, and the panel found that the laboratory serves these groups with distinction. The high level of outside funding is an indicator of highly relevant work. A related indicator is the high level of interaction between laboratory staff and their customers. Attendance is generally good at seminars, workshops, and meetings led and sponsored by the laboratory; staff participation in standards organizations and consortia is strong; and laboratory staff have robust relationships with researchers and users from companies, governmental agencies, and universities.

Another visible measure of the quality and relevance of ITL's work is the number of awards that laboratory staff receive from NIST, the Department of Commerce, and external sources. Examples of internal recognition include a Department of Commerce Gold Medal awarded to three staff members and Bronze Medals awarded to two staff members. Staff members received external recognition from the Federal Bridge Certification Authority and the Laboratory Consortium for Technology Transfer. External awards also included the National Committee for Information Technology Standards (NCITS) Merit and Chairman's Awards; American Physical Society and American Statistical Association fellowship awards; an International Committee for Information Technology Standards (INCITS) Merit Award; a Percy S. Julian Award; and an Arthur. S. Fleming Award. These honors, spread across the various divisions, recognize outstanding technical and program achievement at numerous levels.

ITL's interactions with and impact on industrial customers continue to be strong, and the panel applauds the laboratory's ability to produce and disseminate results of value to a broad audience. ITL primarily serves two kinds of industrial customers: computer companies (i.e., makers of hardware and software) and the users of their products (which include companies from all sectors, the government, and the public). The division reviews in Chapter 15 contain many examples of how ITL makes a difference to industrial customers. For example:

- NIST's familiarity with the networking community and its reputation for an unbiased technical approach are useful in defining the technical matters on which the standards bodies should focus. One recent impact is the Advanced Networking Technologies Division's leadership within the Internet Engineering Task Force (IETF's) investigations of Domain Name System Security (DNSSec) and Internet Protocol Security (IPSec), cumulatively leading to the publication of seven IETF requests for comments.
- The usability reporting work done by the Information Access Division has involved strong industry participation in defining and using the Common Industry Format (CIF) standards. The certification by the American National Standards Institute (ANSI) and the ongoing ISO process mean that standards will be more widely adopted in the future. NIST's work contributing to the growing recognition of usability as a key component of software procurement is important.
- The Software Diagnostics and Conformance Testing Division leads several laboratory-wide initiatives in health informatics that promise to be of significant consequence to the health care delivery community.
- The Statistical Engineering Division has been involved in the establishment of baseline data sets to be used in the assessment and evaluation of the computational accuracy of statistical software. In the

area of key comparisons, the division is working directly with CIPM, national metrology institutes, and regional metrology organizations to establish sound statistical principles for the determination of the basis for global transactions using various measurement standards of different nations.

- The Computer Security Division's Cryptographic Module Validation program has demonstrated its effectiveness in improving the security and quality of cryptographic products. About 50 percent of the cryptographic modules tested had security flaws, and over 95 percent had documentation errors. About 25 percent of the algorithms submitted for evaluation had security flaws, and over 65 percent had documentation errors. Detecting these problems enables vendors and implementers to correct their products before the modules and algorithms are put into production and bought and used by consumers.
- Thousands of scientists use the mathematical resources of the Mathematical and Computational Sciences Division's Web site annually. The division's Digital Library of Mathematical Functions will be a very relevant tool for use by the scientific and engineering communities.

The federal government relies significantly on ITL's products and expertise and often uses NIST standards and evaluation tools to guide its purchase and use of information technology. Salient examples include these:

- The Computer Security Division's Cryptographic Module Validation program has enabled purchasers, including the U.S. government, to be sure that the security attributes of the products they buy are as advertised and appropriate.
- The Information Access Division's Retrieval Group has a wide range of customers. Government agencies (most notably the Advanced Research and Development Activity of the intelligence community and the Defense Advanced Research Projects Agency) work closely with the Retrieval Group to evaluate the success of new information access technologies funded by their programs. In addition, hundreds of participants from government agencies, industry, and academia take part in the annual TREC program. Participation in TREC continues to increase, and it evolves as new tracks are added and old ones are phased out to reflect emerging retrieval challenges. The Retrieval Group's expertise and experience in developing new evaluation frameworks are highly valued by government agencies and are critical in evaluating the success of new technologies. TREC's customers are more diverse, including industry and academia in addition to government agencies. In addition, the division's Image Group has responded rapidly to address requirements of the USA PATRIOT Act of 2001 to design a test program and compile a large test set of fingerprint and face images.
- The biometrics work done at NIST is contracted to it by government customers and is highly relevant to homeland security needs. The effectiveness of much of the current work related to homeland security cannot be measured as yet. However, NIST biometrics contracts demonstrate that the customers believe the group to produce effective results.

Much of the Information Technology Laboratory's work supports multiple types of customers (e.g., industry and government). For example, the new equipment created by the Convergent Information Systems Division for image quality analysis, biometrics, and quantum laboratories is critical to the success of industry and government progress in these areas. Web site statistics also suggest the external relevance of the Computer Security Division. From January 2002 through February 2003, approximately 1.3 million Web site requests were handled each month.

In addition to strong relationships with customers in industry and in the federal government, ITL has traditionally placed significant emphasis on effectively serving its customers within NIST. Collaborative work is highlighted above and is discussed in detail in the division reports in Chapter 15. Beyond these collaborative efforts, the Statistical Engineering Division conducts an outreach and education effort, providing courses on an ongoing basis as well as excellent resources, such as the *NIST/SEMATECH e-Handbook of Statistical Methods*, supporting the NIST community and beyond.

Challenges and Opportunities

The examples mentioned above highlight the Information Technology Laboratory's high level of relevance and effectiveness, its very good customer connections, and its outstanding work in leveraging technology ideas across customer areas. Continued success should involve consideration of challenges, obstacles, and questions to be addressed, such as the following:

- The Information Technology Laboratory has achieved a good strategic focus, which is shared and understood across staff. The laboratory should be alert to and avoid natural tendencies to rely on "analyst and favorite customer" relationships when such relationships undermine the strategic focus.
- The laboratory should continue its efforts to align its strategic focus with the overall NIST strategic plan, especially in areas such as knowledge management and manufacturing optimization. This effort should be carried out at the strategic level with the engagement of the cognizant laboratory directors.
- The laboratory engages in projects that are multidisciplinary, both across its divisions and in interaction with other NIST laboratories. Examples include biometrics, quantum computing, security, modeling, statistics, and pervasive computing. The laboratory staff and management have expressed a clear understanding of the multidisciplinary aspects of such work, and this understanding should be formalized in program management that shows methods and plans for inter- and intralaboratory multidisciplinary collaboration.
- Measures of effectiveness can be elusive and, without clearly expressed underlying assumptions, misleading. Not all measures are appropriate for all activities. The panel commends the efforts by laboratory staff to develop and try out such measures. The panel also suggests that the laboratory management and staff consider whether it would be useful, generally or for specific projects, for the panel to interact directly with customers, who might be able to provide useful feedback pertaining to the effectiveness of the laboratory. Customers might be able to suggest metrics that can be used to demonstrate the value of technology dissemination, and customer feedback might constitute pertinent data for a metric currently used by NIST.
- The laboratory serves many customers. Which customers are most strategically important to the laboratory, and how should work and dissemination be tailored to the characteristics of specific types of customers? For example, the Mathematical and Computational Sciences Division is performing high-quality work in collaboration with the Building and Fire Research Laboratory in the area of modeling and visualization of concrete hardening; this work supports a fragmented industry that consists largely of small firms. It is important that such work be performed with cognizance of the mechanisms by which it will be introduced to and used by the community; the panel would derive benefit in future briefings from hearing about how plans for the deployment of results are influencing work.
- By what rationale would an appropriate target be defined for the percentage of the laboratory's funds that should come from outside sources?
- The panel commends the responsiveness of the ITL management and staff to the panel's suggested focus on improving the number and quality of publications. The laboratory has certainly done so. However, the panel recognizes that journal publication, a commonly accepted metric for effectiveness in scientific disciplines such as physics and chemistry, is likely not the most effective metric for some

areas of computer science, for which presentation at top-level conferences is a more appropriate metric. This distinction needs to be widely understood within ITL and NIST to ensure that proper recognition for researchers is achieved.

The panel also urges the Information Technology Laboratory to vigorously address three important issues highlighted in the 2002 report:

1. A primary traditional responsibility of ITL has been to provide IT support for all of NIST. The relevant activities—which include the support and maintenance of campus networking, personal computers, administrative applications (such as accounting software), and telephones—were traditionally performed by the Information Services and Computing Division of ITL. During the past year, the IT responsibility was transferred from ITL to a separate unit, Technology Services, headed by a chief information officer who will report directly to the NIST director. Since a significant challenge for the ITL involved convincing the NIST laboratories to embrace consistent, institution-wide standards for IT systems, raising the Technology Services unit to a level equivalent with that of the laboratories was expected to provide needed visibility for the issue. Achieving acceptance of this new unit and of centralized IT support across NIST remains a serious challenge; this approach will be a cultural shift for NIST.

Making the IT services component of NIST a separate unit rather than a division of ITL may bring it closer to other laboratories; however, it is important that this unit maintain close ties with ITL programs. For example, some of the work being done in the Computer Security Division can and should be applied to the security of the NIST system. Work on technologies for meetings can be tested and used effectively throughout NIST. Applying the development work of ITL's research divisions to NIST as a whole will require the continued tracking by the CIO office of relevant, ongoing projects, as well as recognition in ITL of the potential for using NIST as a whole as a testbed. The Information Technology Laboratory should maintain interaction with and support the efforts of the now-separate CIO office.

2. Programs such as the work on biometrics, especially face recognition, highlight a question relevant to many information technology activities: In what context will technological advances be used? Information technology is often an enabling technology that will produce new capabilities with expected and unexpected benefits and costs. Although ITL focuses primarily on technical questions and technical quality, it is important that the laboratory demonstrate recognition of the context in which new technologies will be applied so that the results of its work will be taken seriously in the relevant communities. This context has two elements: the deployment of the technology and its social implications. The deployment questions relate to the functionality of the systems in which new technical capabilities will be used. A testbed is not necessarily meant to determine the "best" technology but rather the one that works well enough to meet the needs for which the technology is being developed. Often, the process of considering the possible applications of a technology results in a broader appreciation of the potential benefits. For example, appropriate security is actually an enabler that allows e-business, the globalization of work, and collaboration across geography.

Understanding the goals for new technologies relates to addressing their social implications. For example, maintaining security has serious implications for privacy. The panel emphasizes that in many of the ongoing programs—such as the work on the potential use of face-recognition technologies in security systems in public places—ITL staff have made long and arduous efforts to comply with existing privacy legislation. However, when describing the capabilities and benefits of technological advances to public groups (such as the panel), staff should also be sure to take the time to acknowledge related privacy issues and describe potential social implications. This concern extends to many significant ongoing areas of work at the laboratory, including biometrics (especially face and voice recognition) and voting technology (with special concerns for system integrity and privacy).

3. In last year's assessment report,[2] the panel expressed concerns about industry trends in standards development that would affect ITL's ability to effectively and openly help industry adopt the most appropriate standards for emerging technologies. The growing use of consortia and other private groups in standards development processes places a burden on ITL, which has to strike a balance between its obligation to support and encourage open processes and its need to be involved as early as possible in standards-setting activities so as to maximize the impact of ITL's experience and tools. In some cases, a delicate trade-off must be made between participating in a timely way in organizations that will set standards for the industry and avoiding endorsement of standards set by exclusive groups. ITL's role as a neutral third party and its reputation as an unbiased provider of technical data and tools have produced a significant impact in many areas and should not be squandered by association with organizations that unreasonably restrict membership. Though the situation has not changed materially since last year, there is some indication that consortia are, due to a proactive stance by NIST, addressing participation issues affecting NIST; the Java Specification Participation Agreement is cited as a model.

The panel continues to urge ITL to refine and implement its policy to help divisions decide when participation in closed consortia is appropriate and to consider how NIST can encourage industry to utilize open, or at least inclusive, approaches to standards development. Given that consortia, in some form or another, are here to stay and that in some cases it will be vital for NIST to participate in them, the panel supports recent ITL and NIST efforts to work on the internal legal roadblocks to participation, and it urges continued and expanded efforts to educate external groups, such as consortia members and lawyers, on ways to facilitate NIST's timely participation and technical input. This effort requires customer outreach as well as resolution of legal issues.

Laboratory Resources

Funding sources for the Information Technology Laboratory are shown in Table 8.1. In January 2003, staffing for the laboratory included 247 full-time permanent positions. There were also 96 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The panel notes that the funding for the laboratory has been flat or declining in the face of growth in requirements, some of which—like the unfunded homeland defense mandates—are at a very high level. This situation, predicted to continue for the near future, demands careful strategic planning and prioritization and increases the importance of well-managed collaborative activities and of applying the tests of relevance and effectiveness to ongoing tasks. The Software Diagnostics and Conformance Testing Division has demonstrated particular adroitness at identifying and closing tasks that have effectively completed their usefulness, and this division's approach might be usefully examined by other divisions.

The panel has observed and laboratory staff have explicitly stated that morale is at an all-time high in ITL, due in large part to the director's leadership style and direction. The panel reemphasizes its recommendation, offered in the FY 2002 assessment report, that NIST leadership focus on communicating clearly with staff about the selection criteria for new hires and the progress being made in the search and hiring process. Sharing relevant information will certainly help ensure a smooth transition.

[2]National Research Council, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2002*, National Academies Press, Washington, D.C., 2002.

TABLE 8.1 Sources of Funding for the Information Technology Laboratory (in millions of dollars), FY 2000 to FY 2003

Source of Funding	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (actual)	Fiscal Year 2003 (July 2003 estimate)
NIST-STRS, excluding Competence	31.9	44.4	46.7	42.0
Competence	1.6	1.1	1.7	1.1
STRS—Supercomputing	12.0	11.9	—	—
ATP	2.4	2.3	1.9	1.5
Measurement Services (SRM production)	0.0	0.1	0.2	0.2
OA/NFG/CRADA	9.9	12.2	12.2	16.1
Other Reimbursable	1.6	1.0	29.4	0.0
Agency Overhead	16.4	18.4	—	—
Total	75.8	91.4	92.1	61.0
Full-time permanent staff (total)[a]	381	368	401[a]	247

NOTE: Funding for the NIST Measurement and Standards Laboratories comes from a variety of sources. The laboratories receive appropriations from Congress, known as Scientific and Technical Research and Services (STRS) funding. Competence funding also comes from NIST's congressional appropriations but is allocated by the NIST director's office in multiyear grants for projects that advance NIST's capabilities in new and emerging areas of measurement science. Advanced Technology Program (ATP) funding reflects support from NIST's ATP for work done at the NIST laboratories in collaboration with or in support of ATP projects. Funding to support production of Standard Reference Materials (SRMs) is tied to the use of such products and is classified as Measurement Services. NIST laboratories also receive funding through grants or contracts from other [government] agencies (OA), from nonfederal government (NFG) agencies, and from industry in the form of cooperative research and development agreements (CRADAs). All other laboratory funding, including that for Calibration Services, is grouped under "Other Reimbursable."

[a]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2002, when it is as of March (due to a reorganization of ITL that year). The staff total for 2003 reflects the transfer of 257 full-time permanent staff members to the CIO organization, as well as staff changes in other divisions.

The existence and use of NIST North is a perennial issue. The panel recognizes that the quality of the space in NIST North is significantly better than that available on campus; however, access to these improved facilities does not currently compensate for separating the Mathematical and Computational Sciences Division and the Statistical Engineering Division from the rest of the campus. The separation inhibits informal interactions of the staff of these two divisions with their collaborators in the other laboratories on the main campus; this is particularly problematic for new staff, who are faced with the special challenge of developing collaborations. Although NIST management is addressing the issue, the panel continues to note that a mix of systems, taking into account technological and social factors, could help compensate for the separation. Information technology tools such as videoconferencing, Web collaboration packages, and Web broadcasting can support nonphysical interactions, although regular, scheduled, and subsidized opportunities for face-to-face meetings are necessary to make these technical solutions most effective. These approaches are applicable to the NIST North/main campus gap, as well as to the Gaithersburg/Boulder divide. The Information Technology Laboratory should be adept at demonstrating such tools for its own use and that of other laboratories.

A second facilities issue raised in the FY 2002 assessment report and repeated this year is the substandard network connectivity of NIST to the outside world; laboratory staff noted the advantages of Internet 2 connectivity, which should be explored.

The panel met with staff in skip-level meetings (sessions in which management personnel were not present). These meetings confirmed the impression, also conveyed universally by staff and management who presented their work to the panel, that morale is very high: staff consider ITL an enjoyable place to work and appreciate its positive attributes, such as opportunities for career growth and training, respect for the individual, stability, an appropriate level of flexibility, a focus on visible results, and connection to a world-class bank of expertise at NIST. The panel applauds laboratory and division management for creating such a positive work environment. The panel did note a small set of staff uncertainties (specifically, confusion about intellectual property processes, anxiety about potential staffing impacts of Office of Management and Budget Circular A-76, concern that outsourcing of infrastructure support may make it unreliable, and concern that junior staff be mentored effectively to establish connectivity with customers) and recommends that laboratory management provide clear explanations to alleviate uncertainties.

Laboratory Responsiveness

The panel found that, in general, ITL has been very responsive to prior recommendations and observations. The panel's comments appear to be taken very seriously, and the suggestions made in the assessment reports are often acted on, especially as they relate to the redirection and conclusion of projects. When advice is not taken, ITL usually provides a good rationale for why a given action has not occurred. Examples of positive responses to suggestions made in last year's report include these:

- The Convergent Information Systems Division addressed funding shortfalls, devoted additional attention to student interns and guest researchers, expanded involvement with external organizations, improved the flexibility of its business plan, performed impact studies to describe the impact on industry or society of several of the division's projects, and improved the content and usability of its Web site.
- The Mathematical and Computational Sciences Division strengthened its strategic planning, expressing recognition that the demand for its work is increasing more rapidly than its resources. The division also tracked the life cycle of programming projects by creating ratings for projects depending on the maintenance level.

Part III
Division-Level Reviews

Part I of this report presents the overall assessment of the NIST Measurement and Standards Laboratories. Part II provides a laboratory-level assessment of each individual laboratory. This part presents a technical review at the division level for each laboratory.

9

Electronics and Electrical Engineering Laboratory: Division Reviews

ELECTRICITY DIVISION

Technical Merit

The Electricity Division's work encompasses the development and maintenance of national electrical standards. It aims to identify needs related to electrical standards that have the highest economic impact, require support to industry, and meet the deliverables appropriate to the overall division mission. Six fields of technology are affected by the work of the division: national electrical standards, low-frequency systems, electric power, display metrology, electronic data exchange, and semiconductors.

There is some concern within the panel that important elements of the division's efforts, while clearly of value to the broadly stated goals of its mission and supported by its management, are inadequately reflected in the division's mission statement. These elements include standards and metrics for flat panel displays, standardized systems for the digital transfer of electrical and mechanical manufacturing data, and the maintenance of a sound database of information pertinent to NIST through the organized, electronic capture of data.

As in the past, the division conducts its business in a manner that supports its stated mission. In accord with the division's strategic planning, its three groups were reorganized this past year into four groups: the Electronic Instruments and Metrology, Fundamental Electrical Measurements, Electrical Systems, and Electronic Information Technologies Groups. Eleven major projects (see the subsections below) are supported by the work of these groups.

The panel commends the Electricity Division of the Electronics and Electrical Engineering Laboratory (EEEL) for its management approach. Last year's reorganization of the division's efforts was aimed at better allocation of available resources, which resulted in some redirection. This process was conducted

NOTE: Chapter 2, "Electronics and Electrical Engineering Laboratory," which presents the laboratory-level review, includes a chart showing the laboratory's organizational structure (Figure 2.1) and a table indicating its sources of funding (Table 2.1).

in a manner that effectively utilized staff input, and it continues to be perceived by the staff as a positive exercise. Management is currently building on these efforts with review and planning activities that will maximize the adaptability of the division while retaining its ability to meet its traditional and established responsibilities. The balance that has been achieved between these two occasionally conflicting objectives appears to be well considered and effective. The status of client services continues to evolve. The panel observed services that were in the process of elimination as well as new services that had been developed in response to clients' requests. In both cases there was clear evidence that clients were being consulted throughout the process.

In the opinion of the panel, the strategic decisions of the division's management and staff have considerably improved the division's ability to meet its goals and objectives while maintaining its overall level of technical merit. An example of the division's overall approach can be seen in its yearly pamphlet, which describes each project and enumerates a number of specific short- and long-term objectives. In its consultations with staff, the panel found that these objectives represent realistic goals and plans and are considered seriously. Although there may be occasional questions by staff about the value of the time spent producing these documents, such questions are to be expected from a committed staff determined to maximize the level of its efforts. The effort put into this planning and documentation, however, is of considerable value and should be recognized.

In the following subsections, details of major projects in the division are discussed in order to illustrate the high quality and technical merit of its work.

Electronic Kilogram

The objectives of the Electronic Kilogram project are the realization of the electrical unit of voltage and an investigation of an alternative definition of the unit of mass that is based on measured quantities determined by the fundamental physical constants of nature. The unit of mass is currently based on a physical artifact, whose copies differ by non-negligible amounts. Numerous national bureaus of standards are making efforts to replace these artifacts. The program at NIST is at the forefront of such efforts and retains U.S. leadership in the field of standards.

The level of both technical skill and design creativity for this project is exceptionally high. The experimental setup is an exceedingly difficult apparatus to develop and refine. The project combines the use of a number of existing electrical standards (the volt and the ohm) in order to generate a known force through means of a complex, yet fundamentally deterministic, magnetic system. The instrumentation has recently undergone a series of technical improvements, including the redesign of various elements. The benefits of these changes are expected to be established through testing that will occur shortly. The level of technical skill and expertise brought to the project is clearly evident in the identification and subsequent elimination of a number of design elements that contribute to systematic errors in the system. This is the sort of measurement system that NIST can be proud of, for the system is clearly a leader among the various efforts in the world.

Voltage Metrology

The Voltage Metrology project maintains the U.S. legal volt and disseminates the unit as an internationally consistent, accurate, reproducible, and traceable voltage standard that is readily and continuously available for the national scientific and industrial base. NIST has historically been one of the world leaders in the determination of the volt and has led the way in the development of hysteretic Josephson arrays, which are in use in most technologically developed countries around the world.

Besides simply maintaining and disseminating the volt, this project has continued to refine the Josephson array device and to reduce its size and complexity so that it can be used as a portable device. It is now clear that interlaboratory comparisons based on traveling Zeners are limited primarily by the instability and noise of the Zener diode transfer devices. The project has developed and tested a portable Josephson array standard. Recent publication of these results indicates an improvement of about a factor of 10 over conventional traveling Zeners and provides this improvement directly to NIST's most important clients. Interesting studies about the spectral analysis of typical Zener devices are under way. This work promises to help optimize the measurement conditions but also serves as a valuable educational tool for clients of the Voltage Metrology project.

The project is utilizing a programmable array for the voltage calibration services provided to its customers. EEEL enjoys a steady demand from its customers for calibration of saturated cell voltage standards. At one time it was hoped that the evolution of the Zener diode reference standards might improve the state of the art and make high-level voltage calibrations much easier. However, over the years the Zener-based devices have shown unpredictable noise characteristics, which diminish their value as a highly stable voltage standard. The development and testing of the programmable Josephson array have uncovered a number of minor technological problems, most of which are now solved, illustrating improved collaborations with the NIST Boulder campus.

Single Electron Tunneling

The goal of the Single Electron Tunneling project is to develop applications for single-electron tunneling (SET) technologies, which are relevant to high-precision electrical metrology. A recent collaboration with the capacitive standard effort in Gaithersburg has resulted in advances in the state of the art for determination of frequency dependencies inherent in capacitance measurements; these advances are fundamental to this project. The limited level of staffing available for this work makes it essential to secure and maintain strong networks. Effective collaboration with NIST Boulder as well as work with a group in Japan and with investigators at the University of Maryland have all proven effective.

Metrology of the Ohm

The Metrology of the Ohm project maintains the U.S. legal ohm through distribution of an internationally consistent, accurate, reproducible, and traceable resistance standard that is readily and continuously available for the U.S. scientific and industrial base. NIST continues to be a world leader in the realization of the ohm through state-of-the-art technology such as the quantum Hall (QH) resistance device. The QH devices are manufactured by NIST. However, these current devices degrade over time, so NIST has had to work diligently to ensure that there is an adequate supply of them. The level of signal produced by the QH devices is very small and difficult to use. In addition, the system to realize the ohm through the device is expensive and difficult to use. The Metrology of the Ohm team has taken on the task of trying to develop a QH device that will be less expensive and easier to use. If successful, this project may make it possible to do QH resistance work in the field.

Over the whole range of resistance measurements, NIST has always had a world-respected reputation. If NIST could be faulted, it would be related to its slowness to utilize cryogenic current comparators and other developments in resistance metrology. It is pleasing to see that this situation is changing. This project's recent focus on high resistance is beginning to reap dividends. Improved scaling to 1 megaohm using a new cryogenic current comparator, stable resistance standards with much-improved temperature coefficients, higher-value Hamon transfer standards, and the active-arm high-resistance bridge are all significant developments. Taken together, they redefine NIST preeminence in high-resistance metrology.

AC-DC Difference Standards and Measurement Techniques

The AC-DC Difference Standards and Measurement Techniques project exists to provide U.S. industry with a link between direct current (DC) and corresponding alternating current (AC) electrical standards and to maintain and improve national standards for measuring DC and AC differences. The project team has undertaken a number of innovative development projects designed to utilize state-of-the-art thin-film approaches and technologies in order to facilitate the production of standards. This is a very challenging technical task, and there has been significant progress in a number of directions. Based on the achievements of this group, it is clear that the technical skill and commitment of its personnel are of the highest caliber.

Impedance and AC Ratio Standards

The Impedance and AC Ratio Standards project maintains and disseminates the U.S. legal farad and relates that unit to the International System (SI) of units. It provides the U.S. industrial base with consistent, reproducible, reliable, and traceable electrical calibrations in these areas. Recent work on improving the accuracy of frequency dependence measurements of capacitors is a significant advance not only for U.S. manufacturers but also for the metrology community as a whole. Many other countries trying to solve similar problems will welcome these results.

The calculable capacitor continues to be the focus and foundation of this project. It is important not just as the fundamental capacitance standard but also in its role in the “quantum triangle,” linking the single-electron tunneling, watt-balance, Josephson, and quantum Hall experiments. Other advances, such as the new straddle bridge for measuring voltage ratio, augment and improve the measurement and scaling of the AC impedance units and emphasize the high motivation, originality, and competence of the staff.

The initiation of an AC quantum Hall resistance experiment places NIST in the company of only four other laboratories in the world, demonstrating that NIST is seriously addressing these measurement challenges and is committed to moving beyond its past successes.

Electric Power Metrology

The Electric Power Metrology project exists to maintain and disseminate precise electrical measurements for the nation’s electric power transmission and distribution systems and various industrial high-energy power applications such as welding. It maintains standards for power and energy and provides calibration services for AC and DC, electric power and energy, and other electrical purposes.

The panel commends the project team for maintaining close ties with industry and other standards organizations and for its leadership in these relationships. The project shows a management commitment to satisfying both its major clients and overall NIST objectives. Its technical achievements are significant and are respected nationally and internationally. Developments such as the distorted power test are not just technically innovative but also tailored to be of immediate service to NIST’s clientele. The project’s calibration services continue to be in demand and without any significant complaints. In general, this project seems to have struck a good balance between ever better identification of uncertainties and satisfaction of clients’ needs.

Time Domain Measurements

The Time Domain Measurements project exists to expand and improve present NIST time domain waveform measurement services to support high-performance samplers and digitizers, as well as fast pulse and impulse sources, operating at frequencies from DC to 50 GHz. The work of this project team clearly lies at the limit of what is achievable with current instrumentation. The personnel in the project team have been able to develop methods permitting the calibration of a commercially available instrument to such a degree that the instrument can then be used as a tool for the calibration of other instruments. The expertise and technical capability demonstrated in this work are exemplary. This project's efforts in support of NIST's homeland security work have been extremely valuable, leading to the development of guides and published standards for metal detectors.

Flat Panel Display Metrology

The objective of the Flat Panel Display Metrology project is to develop robust, reproducible, and unambiguous metrology methods to characterize electronic displays, particularly flat panel displays (FPDs) to support the domestic industry of display users. The project involves the development of patterns for display measurement and the revision of International Organization for Standardization (ISO) visual-display ergonomic standards.

Other current work has a focus on homeland security. These efforts involve the development of measurement techniques dealing with reflectivity and with a liquid lens that can distinguish features in shadow in a high-contrast field of light and dark.

The Flat Panel Display Metrology project is creating standard approaches to measuring display characteristics. Despite the long time that displays have been in existence, the technology is in its infancy. Expensive techniques are used in industry to measure display characteristics; the results from manufacturer to manufacturer are ambiguous in many cases. The NIST team has found inexpensive ways to make the same measurements and has developed standards for metric measurement methods (as opposed to metric standards). The expectation is that through standardization of measurement methods that produce unambiguous results, standard sets of metrics will evolve.

It is noteworthy that this project team is applying creative techniques to the needed development of low-cost and effective metrics. Industry is responding positively to this work. NIST should continue this project, which has such high leverage in terms of output versus manpower. The aims of the project should be embodied in the division mission statement.

Infrastructure for Integrated Electronic Design and Manufacturing

The objective of the Infrastructure for Integrated Electronic Design and Manufacturing project is to actively contribute to the technical development of neutral product data exchange specifications, manufacturing specifications, and component information infrastructure for the electronics industry. The project focuses its efforts on two areas: Electronic Commerce of Component Information (ECCI) and Internet Commerce for Manufacturing (ICM). The skill base for this project requires knowledge of digital systems and software development.

As technology advances in ways that permit the digital transfer of electrical and mechanical manufacturing data, the need for standardized ways to represent the data becomes an imperative. To let these techniques develop in a random manner puts the United States at a competitive disadvantage. The panel commends NIST for recognizing the need for this project.

The project is at a critical stage of development requiring high skill levels of professionals. The state of the art for electronic design and manufacturing does not have standards for representing electrical and mechanical manufacturing data to create the much-needed infrastructure. The infrastructure depends on such standard representations and libraries of component parts, which contain the detailed data. There are at present many such libraries and data representations, with no single standard. The industry may never be able to reach agreement on such standards, but NIST—as a neutral body with the integrity and knowledge to minimize the disarray—can be a positive, industry-wide force. An alternative approach to reaching industry-wide agreement would be to make known the various infrastructures and data representations and then to create a basis for transformations among the data representations. The NIST project is attempting to address many aspects of this problem area. The NIST participants have the knowledge base to contribute solutions.

The NIST ECCI and ICM focus areas within this project are recognized as extremely important by the electronics industry. The fact that numerous standards groups meet frequently to reach agreement in these areas exemplifies the importance of the work. Standards group meetings sponsored by the Electronics Industry Association (EIA) and the Institute of Electrical and Electronics Engineers (IEEE) as well as many industry ad hoc standards groups are well attended by industry representatives. Because of the technical skills and neutrality brought to standardization efforts by NIST scientists in this area, they are welcomed and encouraged by industry. Within some standards organizations, the NIST personnel assume a leadership role.

Knowledge Facilitation

The Knowledge Facilitation project provides a formalization to achieve secure and cost-effective means of data collection and dissemination. The three stated objectives of this project are as follows:

- To eliminate paper-intensive and manual operations by automating tasks, decreasing the administrative requirements of the technical and support staff, increasing responsiveness to customers, and implementing a secure NIST paperless environment.
- To provide information technology security policies, procedures, guidelines, and baselines and ensure compliance with Government Information Security Reform Act (GISRA) requirements.
- To develop and refine a workflow application to enable the automatic tracking of technical and administrative calibration information.

The first objective is actually a mission statement encompassing the other two objectives; the second objective relates to homeland security; the Information System to Support Calibrations (ISSC) satisfies the third objective, by reducing the percentage of time that NIST scientists and support staff spend producing the necessary calibration forms and associated reports. The Knowledge Facilitation project addresses a key need in the complex world of NIST and has to be shown explicitly as part of the NIST mission. The skill base for this project requires knowledge of digital systems and software development.

Progress in this project significantly improves the ability to manage calibration data, to report calibration work, and to interact with NIST customers with respect to calibration data. An outgrowth of this work is its logical extension to capturing technical report references in a consistent database to greatly simplify browsing and access. The concepts embodied by this project should be captured in the division mission statement. NIST is to be commended for formalizing this critical project.

The Knowledge Facilitation project has been developed nearly to the point that one of its deliverables, the ISSC, will be moved to another NIST area, Technology Services, which has the ability to call on experts should problems arise. ISSC capabilities are now accessible throughout the division and EEEL.

Program Relevance and Effectiveness

A major activity of the Electricity Division is the maintenance of highly accurate and reliable electricity standards. These standards enable robust measurements of the entire range of electrical quantities that are needed to support commercial infrastructures and technology development as well as advanced investigations at academic institutions. Representations of the volt and ohm are the practical means through which NIST's electrical units are maintained. Participation in international comparisons and linkage to national traceability systems are also key to NIST's fulfillment of metrology obligations and to the preservation of the prestige and respect it receives from other countries and metrology organizations. The maintenance of the legal unit of the volt and its dissemination are at the heart of the charter of NIST. The development and implementation of a reliable current standard are also clearly consistent with the division's central mission. This effort combines project work with efforts necessary to implement the use of the current standard: the development of a stable capacitive standard. While this project involves significant technical risk, success would essentially be revolutionary in the field of electrical standards. Other important projects within NIST are also dependent upon the Josephson junction array voltage standard work carried on by the Voltage Metrology project. For example, the watt-kilogram experiments in both the United States and France are using Josephson array devices built by the NIST Voltage Metrology team.

Metrology of the ohm and resistance calibration services likewise are part of NIST's core business and are key to U.S. industry. Realizing the value of the ohm is an essential component in the foundation of international trade. While stark numbers may often misinterpret relevance, the large number of resistance calibrations is surely a positive indicator that NIST's Metrology of the Ohm project is extremely relevant to U.S. industry.

The work of the AC-DC Difference Standards and Measurement Techniques project is fundamental to the use of electric power. Nearly every type of industry using electric power or electronics in any form has some need for accurate measurement based on thermal converters and AC current shunts. These needs vary widely in terms of both the frequencies and the amounts of current involved and create a critical need for standards and calibration services covering a wide range of both frequency and current domains.

The perpetuation of a dependable, consistent, and traceable standard for the farad will continue to be a core priority for the Electricity Division. There are only about five calculable capacitors in routine operation in the entire world; the NIST system claims to be the best and so far has been able to substantiate those claims. This unique situation enhances NIST's international reputation but also implies additional responsibility for maintaining the current level of accuracy. The division is currently engaged in extending the range and accuracy of capacitance measurements. Generally, NIST's capabilities meet industry needs but do not exceed them by a large margin. The Impedance and AC Ratio Standards project's recent studies into the frequency dependence of standard capacitors illustrate that the project is responsive to U.S. clients' needs and demands.

Conventional power measurements and their dissemination are handled competently and professionally by the division. Power and energy metering has undergone several improvements. The power calibration facilities have been upgraded with more modern equipment. Tests of distorted power to the 50th harmonic have been developed to answer demands for traceability and calibration. Two projects, those on power quality and high voltage, are under consideration for discontinuation because they no longer appear to be of interest to the division's clients.

Of particular note in the area of conventional power measurements is a small project focused on communication security within the power distribution grid. The approach undertaken was to develop a tool characterizing the varying real-time latency timings of control communications primarily of remote power-producing facilities. This tool should help the industry assess the impact of such things as denial of service within control loops that stabilize and equilibrate the national grid of electrical power. Recently increased attention to counterterrorism has focused on this vulnerability to our electrical energy distribution system, and its impacts on homeland security are direct and potentially enormous.

The Time Domain Measurements project focuses on electrical measurements at timescales at the limit of present instrumentation. This work currently supports a very large industry dependent on the special need to interface electrical components and instruments with high-bandwidth optical communications.

The metrology for flat panel displays is still in the infant stage. NIST is providing a much needed function by bringing industry and consumers together to work on the problem while contributing positive steps in the evolution of that metrology. NIST experts have developed a set of measurement techniques that will ultimately lead to metrology standards for flat panel display. While industry is willing to accept the techniques, it is not yet ready to accept certain standards. Nonetheless, the value of this work is recognized, given that a NIST-supplied, complete set of patterns for display measurements and the setup for all pixel-array formats currently in use (approximately 40,000 patterns) have been accepted by the Video Electronics Standards Association. The Flat Panel Display Metrology team has also developed a unique approach to photographing high-contrast scenes, using a liquid-filled lens, so that the features of a face in shadow can be seen even when the background is very bright (a normal camera does not "see" the face in shadow, showing just a silhouette). This approach is being applied to homeland security measures.

The work being done by the Infrastructure for Integrated Electronic Design and Manufacturing team is very significant and of great importance to the electronics industry. Standards for the description of electronics data are imperative in order for the United States to maintain and enhance its position worldwide in the electronics industry. The team consists of both experienced and relatively young researchers. As they develop the infrastructure, their enthusiasm for the task leads to rapid learning and understanding of the issues involved and the types of solutions needed. As the electronics industry is evolving rapidly, the problems are not "solved"—instead, researchers are hard-pressed to keep up with solutions for the evolving problem set. As the team's understanding of a problem grows, the recognition of solutions that need work in order to be implemented also grows. Thus, an adequate staff of researchers is essential. In the present NIST climate, maintaining an adequate research staff for this project is difficult.

The Knowledge Facilitation project members continue to remain involved with industry standards organizations. Their industry colleagues recognize the work of these individuals at NIST. The team has developed software tools to manipulate the data contained in an IPC (an industry standards organization) standard format. The project members interact with such industry standards groups as the International Electrotechnical Commission TC93, the Electronic Design Automation Standards Technical Commission, IPC, and the IEEE Computer Society Design Automation Standards Committee. The work performed by NIST covers an important, yet small, part of the total problem space. One of the key efforts under way concerns an experiment: international interoperability testing of electronic component information and dictionary harmonization. An electronic component information dictionary is key to the ability of semiconductor and electronic parts producers and users to communicate what is available and what is needed in future products. At present, there are many such dictionaries, and harmonization is crucial. Other tasks concern manufacturing information chain management and Web infrastructures to enhance B2B and e-manufacturing processes.

The ISSC has already demonstrated its significance and cost-effectiveness, as exemplified by its widespread acceptance and use throughout NIST. A Web-based bibliographic database, which is a natural follow-on to the ISSC, is now being developed. This database will provide a consistent and efficient method for searches of papers published within EEEL. The security of data and access to data also constitute a major focus of the project. This focus relates strongly to the topic of homeland security.

Division Resources

The funding level of the division has been relatively constant over the past 7 years, but since the cost per employee has risen, it is difficult to keep the same number of technical staff. The overhead has also increased. This situation has led to manpower shortages in several important areas.

Funding and the loss of two key professionals are having a negative impact on the ability of the sparse crew in the Infrastructure for Integrated Electronic Design and Manufacturing project to cover the territory. Morale is also being affected. Though the members of the project team are dedicated and highly enthusiastic, they feel that they are lacking the critical mass to do their job well.

The Voltage Metrology project has had a steady workload fully occupying the small staff of two people. The panel continues to have some concern that there is insufficient other staff having the required capabilities to act as backup for the existing staff. Cross-training is still being considered, but an additional half-person in technical support is sought. There is no extra capacity on this team should any new projects need to be addressed.

The less-than-optimal progress in the Single Electron Tunneling project can be linked to staffing shortages. A significant impediment to the project resulted when leaks in an essential piece of equipment occurred and it was necessary to divert the research of a central investigator to do repairs. Efforts have been made to add staff; however, staffing levels throughout the division are stretched dangerously thin, making it difficult to provide additional staffing for any project. It is expected that more staff would help to alleviate some of the difficulties facing this project.

Both the Metrology of the Ohm and the Voltage Metrology projects are funded and staffed at minimal levels, but the addition of new technical support has brought renewed optimism and direction into this work.

The Voltage Metrology project continues to have inadequate clean electric power, which is essential for the services it provides. Although a reliable backup power generator is now available, the harmonic distortion of the regular power still needs to be addressed.

While the present resources seem just adequate to maintain the calculable capacitor for the Impedance and AC Ratio Standards project's work, further advances of this instrument, AC quantum Hall resistance measurements, and automated systems, as well as the upcoming move to the Advanced Measurement Laboratory, will severely tax the project's manpower and financial resources for a couple of years. This project has generally sufficient resources, both in equipment and personnel, to perform its routine maintenance and requested calibration services. The adaptation to the AML and to NIST's internal quality system will be a heavy, but temporary, strain for perhaps the next 24 months. The panel is concerned about the small number of permanent staff within the project and about the ability of the project to maintain a knowledge base sufficient for the smooth continuation of project objectives. Some additional technical assistance was requested for one subproject.

Perhaps the biggest concern with respect to the electric power work was the inability to be responsive to the rapidly changing electric power industry—an industry that is drawing considerable public and government attention. The challenges for a deregulated electric power industry, and in turn for NIST, are not yet fully understood, but NIST's ability to meet these needs as they arise, let alone to provide leadership within the industry, is very limited.

Although current levels of staffing and equipment in the Time Domain Measurements project are sufficient for present industry needs, the team must struggle to maintain its current level of calibration services while doing the development work necessary for anticipated future needs. While the sort of equipment needed for this work can be rather expensive, this project team has proven extremely effective at finding outside resources for equipment costs.

The Infrastructure for Integrated Electronic Design and Manufacturing project requires more people and resources to be as effective as it could be. The project is recognized as important to the work within industry, but staff is spread too thin. The value of the project to U.S. industry is well worth an additional two staff members. At present, the project is working to fill openings in two authorized positions.

To limit the workload, opportunities were seized to delegate work to other organizations where possible. For example, for the voltage interlaboratory comparisons, the role of pivot laboratory was given to the Sandia National Laboratories in the Department of Energy. The division should be commended for this innovation, but it remains to be seen what more, if anything, can be delegated.

The Electricity Division is in the awkward phase of having many experienced staff members retiring. This places an additional training burden on a division that is already aggravated by the gradual decline in its total number of staff.

Although the staff faces substantial challenges with respect to equipment and staffing needs, morale is good and priority work is accomplished.

Evaluations in prior years have repeatedly emphasized the dangers inherent in operating with exceedingly lean budgets. These dangers have not, in the panel's opinion, resulted from funding decisions made within EEEL, where a combination of good management and remarkably committed staff have maintained a very high level of achievement. They are instead the cumulative consequence of years of what has effectively been a reduction in the overall budget—and thus a reduction in the staff. The lean budgets should no longer be considered a danger merely to EEEL's current effectiveness; they now also clearly impact both its current and its future effectiveness.

Examples of the impact of sparse operating funds on the division's effectiveness are available. The Time Domain Measurements project, for one, has turned down homeland security projects owing to the lack of available human resources. The primary researcher on the Gaithersburg Single Electron Tunneling project is forced to spend months of his time dealing with commercial equipment failures. Unavoidable demands for calibration services hamper the essential development of modern AC-DC transfer devices. Each of these examples involves intensely committed staff members whose value is clearly recognized by division and laboratory management and who are actively supported, based on sound judgment, to the degree of current funding capabilities. But limitations on those funding capabilities are now having a direct and negative impact. It must be made clear that this situation will likely not, in the panel's opinion, be addressed by additional reallocation of resources, as has already happened for some projects; because overall resource allocation is so thinly stretched, equally troublesome examples would probably turn up quickly in other programs. The problem is instead related to the overall level of support.

SEMICONDUCTOR ELECTRONICS DIVISION

Summary

Overall the panel believes that the Semiconductor Electronics Division (SED) is doing the best it can to support a broad array of projects relevant to industrial needs, given its personnel and funding limitations and its aging equipment and facilities. The panel emphasizes, as it has for several years, that for NIST to maintain its leadership role in semiconductor metrology, to continue providing key results to industry, to develop important new measurement technologies and standards in advance of industrial needs, and to keep pace with emerging developments in industry and with scientific progress, the necessary infrastructure must be kept in place and continually improved. These efforts are all the more important because NIST may be the only organization that is able to provide meaningful and timely solutions to important requirements for technology development. In short, SED must have continuous access to stable core competencies and infrastructure for state-of-the-art measurements. Access to a properly funded and staffed Advanced Measurement Laboratory facility constitutes a major opportunity for the division to maintain these competencies.

Technical Merit

The mission of the Semiconductor Electronics Division is to provide technical leadership in the research and development of the semiconductor measurement infrastructure essential to silicon and other advanced semiconductor technology needs. The division's programs also respond to industrial measurement needs related to compound semiconductors, microelectromechanical systems (MEMS), power devices, and silicon-on-insulator devices. Several projects are focused on life science applications. A brief overview of the activities of the Office of Microelectronics Programs (OMP) activities is included as part of the SED review, and appropriate comments are included as part of this division report.

The SED objectives are appropriate to its mission and accurately describe the programs currently under way in support of NIST, NIST themes, and the EEEL's missions. A thorough annual strategic planning process aligns SED programs to overall NIST themes, EEEL's strategic plan, and customer needs. Division staff members have an excellent understanding of the problems and needs facing the semiconductor industry and the areas in which NIST's unique skills are most effectively applied. Industry views SED's contributions as unique and essential to efficiently providing measurement techniques and standards. The fact that NIST is in a position to provide methods and standards without commercial bias is seen as extremely beneficial to the industry overall, and that ability is unequaled by any other organization—no other body can provide this unique combination of skills and capabilities.

The International Metrology Working Group sets the metrology requirements in the International Technology Roadmap for Semiconductors (ITRS). SED staff assume leading roles on U.S. standards committees and in the International Metrology Working Group in order to support and encourage new and better methods for meeting critical, industry-wide measurement needs. These methods are being adopted worldwide to support the semiconductor industry's business needs. Examples include the use of NIST Joint Electron Device Engineering Council (JEDEC)-approved oxide-quality measurement methods to verify the uniformity of offshore integrated circuit foundry products.

The panel reinforces the statement above that the overall NIST and SED leadership role requires that core competencies and infrastructure necessary to implement and support state-of-the-art measurement capabilities must continue to be developed in advance of industry needs.

SED's role in the organization of the ongoing International Conferences on Characterization and Metrology for ULSI [ultralarge-scale integration] Technology is seen as a particularly valuable leadership activity. The next of these conferences is scheduled to occur in 2003 and is expected to result in another 700-plus-page, hardbound proceedings volume published by the American Institute of Physics. The volume will be a practical, up-to-date summary of the state of the art in semiconductor measurement science and metrology for use by researchers and in industrial applications.

Research efforts in SED appear to be in balance with its service activity. Since basic research is necessary to successfully complete most SED programs designed to provide service results, by definition a certain level of research is built into most SED programs—for example, in the physical modeling of oxide breakdown characteristics. Fundamental research activity is exemplified by the Nanoelectronics and the Single Molecule Manipulation and Measurement (SM3) initiatives that are currently under way.

Key SED program activity was presented to the panel in formal reviews and through more informal, interactive poster presentations in the laboratories. Project goals, relevance, and results were clearly stated in the majority of these presentations. Benchmarks (performance indicators) were used to clearly communicate goals and progress relative to customer needs. The following subsections discuss specific project efforts.

Advanced Metal-Oxide Semiconductor Device Reliability and Characterization

A major problem challenging the continued advance of complementary metal-oxide semiconductor (CMOS) devices is the exponentially increasing gate tunneling currents through ever-thinner gate dielectrics in successive generations of new technology. Therefore, the semiconductor industry worldwide is anxiously awaiting the development of viable, alternative gate dielectrics to replace SiO_2 in future generations of CMOS technology. The Advanced MOS Device Reliability and Characterization Program within SED continues to play an important role in fostering this development by developing state-of-the-art electrical measurement methods, tools, software packages, diagnostic procedures, reliability data, and models, and by providing leadership to standards organizations such as EIA/JEDEC and the American Society for Testing and Materials (ASTM).

During the past year, this program has made significant contributions in (1) basic mechanisms research (e.g., substrate hot-hole injection study, acceleration parameters for ultrathin SiO_2, negative bias temperature instability under pulsed bias stress); (2) electrical characterization and analysis (e.g., effects of Dit, simulation code, and gate voltage on EOT and CET); and (3) reliability testing standards (e.g., a new JEDEC TDDB (time-dependent dielectric breakdown) standard using noise as a breakdown detection indicator). All of these are highly relevant to customers' needs. The extensive collaborations with industries and universities have undoubtedly contributed to the program's impressive accomplishments, and they should be continued if not further expanded. In light of the pressing needs of the customers (i.e., U.S. semiconductor manufacturers, U.S. standards organizations, and U.S. test equipment companies) for viable, alternative gate dielectrics in the near future, the panel strongly supports the program's emphasis on high-k gate dielectric characterization and reliability in its plans for the immediate future.

Critical Dimension Metrology

The overall goal of the Critical Dimension Metrology project is to develop traceable critical dimension (CD) reference materials with dimensions and uncertainties that meet ITRS roadmap requirements. Implementation goals include fabrication, calibration, and distribution by an outside commercial supplier and delivery in a configuration compatible with the latest metrology tools used by the industry. The 2001 ITRS projects a physical gate length target of 45 nm for manufacturing in 2003, with measurement precision requirements of ±3.7 nm (3 sigma).

In 2002, SED demonstrated three-dimensional CD standards fabricated in single-crystal silicon with nominal widths of 80 nm calibrated to an accuracy of ±15 nm (2 sigma). It should be noted that these three-dimensional structures are calibrated laterally but not vertically, and they have the benefit of simulating actual measurement conditions in the manufacturing area more accurately than do two-dimensional structures. By performing high-resolution transmission electron microscopy (TEM) on the structures, the lateral width, or CD, can be measured directly, counting silicon lattice planes, providing traceability to the lattice parameter. As a result of joint work with International SEMATECH in implementing this standard, it was decided to change the structure from silicon-on-insulator (SIMOX) to silicon bulk material having etch stop properties induced by special wafer doping. This new structure has reduced charge-up problems while being examined in the scanning electron microscope (SEM), the usual method used in manufacturing for CD measurement. However, the fabrication capability for the new materials is not yet equivalent to the SIMOX material. Current fabrication capability produces material with a nominal CD of 180 nm and a calibration uncertainty of ±5 nm (2 sigma).

Since TEM measurements are destructive and expensive, secondary calibration for volume production of standards was to have been done by electrical resistivity measurements correlated to TEM measurements on the same wafer. However, because of edge roughness and other effects, the precision of this method was found to be unsatisfactory, and high-volume CD SEM measurements were substituted for electrical resistivity. The development of atomic force microscopy calibration methods for the replacement of more costly CD SEM measurements is now under way.

SED believes that it can meet roadmap requirements with these new methods and deliver CD measurement standards with nominal 50-nm CD uncertainties of ±3-5 nm (2 sigma) in 2003.

Scanning-Probe Microscopy

The initial goal of the Scanning-Probe Microscopy project is to develop the measurement infrastructure necessary for scanning capacitance microscopy (SCM) to provide two-dimensional dopant profiles of ultrashallow junctions, meeting the ITRS goals, and then to transfer the NIST-developed technology to industrial users by way of software, publications, characterized samples, and collaborative projects with industry. An ultimate goal is to expand this project into a broader base of scanning-probe microscopy-based semiconductor metrology techniques.

Major breakthroughs this year included the identification of stray light from the position-sensing laser in the SCM as a source of noise that was limiting measurement sensitivity. Strategies for controlling this source of noise were identified and implemented, and a superior sensitivity in the mapping of dopant distributions across ULSI semiconductor junctions was achieved. A publication describing the effect and an application for a patent have been submitted. NIST will distribute personal computer (PC)-compatible software for interpreting SCM images (12,000 lines of optimized code, called FASTC2D), along with a descriptive manual and reference samples.

Power Semiconductor Device and Thermal Metrology

A major problem facing the rapidly emerging area of advanced power semiconductor devices is the ability to evaluate the performance and reliability of these devices while they are operating at high voltage, current, and frequency. The Power Semiconductor Device and Thermal Metrology project continues to focus on developing thermal and electrical metrology tools for the characterization of these advanced electronic devices that include, notably, silicon carbide-based power devices. Unique metrology tools have been developed to map the degradation of SiC bipolar devices, measure nondestructively high voltage/current switching failure, monitor thermal properties of high-power packaging and cooling systems, and measure on-chip temperature using high-speed thermal imaging.

Since last year's review, this project's researchers have become fully engaged in the Defense Advanced Research Projects Agency (DARPA) Wide Band Gap Semiconductor Technology Initiative. NIST acted as a coordinator to form the NIST/Army Research Laboratory (ARL)/Naval Research

Laboratory (NRL) Power Device Evaluation Team to evaluate all power device deliverables for the DARPA SiC Wide Band Gap Semiconductor program. In addition, NIST assisted DARPA in defining the deliverables from contractors that will enable the evaluation team to monitor the progress of the program and to make recommendations to the program managers on the future direction of the program. Technically, NIST has tasks addressing the following SiC issues: metrology for mapping SiC power bipolar device degradation, metrology for nondestructive switching failure, and circuit simulator models for SiC power switching devices. NIST also has the responsibility of helping to evaluate the progress of the DARPA SiC Wide Band Gap Semiconductor program and the industry applicability of the SiC devices developed in the program. NIST will coordinate activities with the DARPA Power Device Evaluation Team (NIST/ARL/NRL) and will apply the results from the tasks listed above to develop circuit simulator component models for all of the device deliverables from DARPA contractors. Finally, NIST will provide recommendations to the DARPA program manager and participate in DARPA program reviews.

The project team has used a combination of its MEMS in-house process capability, the standard CMOS system-on-chip (SOC) design and fabrication capabilities of an outside supplier, and the thermal imaging capabilities of its unique thermal imaging microscope to develop a sensitive gas sensor capability for homeland security. A metal-oxide micro-hotplate-based gas sensor is fabricated in situ on the fully processed CMOS SOC. This integrated combination has achieved 100 times better sensitivity than that of previous world-best gas sensors and is easily manufactured at low cost. This project team has characterized the micro-hotplate using its high-speed transient thermal imaging microscope. The thermal imaging microscope has a spatial resolution of 15 μm and a time resolution of 1 μs, providing the capability of characterizing the critical micro-hotplate component of the gas sensor.

The panel is pleased with the formation of several major collaborative efforts that include the following: major corporations that are contractors in the DARPA initiative, DOD laboratories in the formation of the Power Device Evaluation Team, and several universities with leading programs in high-power electronics.

Compound Semiconductor

The panel is also pleased to see continued progress in the development of unique spectroscopic methods that are being used to study novel compound semiconductor device structures (heterojunction bipolar transistor, high electron mobility transistors), with a strong focus on group III nitrides in the application areas of radio frequency (RF), power, and optical electronics. The NIST Compound Semiconductor project has assembled a low-cost, state-of-the-art capability for contactless electromodulation and surface photo-voltage spectroscopy by leveraging the use of existing components from within NIST laboratories at a savings of 80 percent. This technique has been utilized to make the first contactless diffusion length measurement of GaN and AlGaN and will be used to investigate the properties of metal contacts on GaN-based device structures.

With the addition of this expertise, this NIST project has been awarded a joint contract with ATMI (Advanced Technology Materials, Inc.) of Danbury, Connecticut, under the RF Technologies thrust of the DARPA Wide Band Gap Semiconductor Technology Initiative that is focused on providing thickness and composition measurements and standards for 20- to 30-nm AlGaN films on sapphire substrates. This is an across-NIST effort, involving the Materials Science and Engineering Laboratory for X-ray diffraction, electron microscopy, and neutron activation analysis; the Chemical Science and Technology Laboratory for Raman spectroscopy; and EEEL for optical and spreading resistance measurements. EEEL's effort involves a unique system being developed in the Semiconductor Electronics

Division and the Optoelectronics Division for mapping spreading resistance and metal contact resistance across wide band gap materials films with 40-μm spatial resolution.

The panel is pleased with the direction of the NIST team, the progress in the development of a state-of-the-art laboratory, the acquisition of DARPA funding, and the growth of collaboration among NIST laboratories, universities, and industry.

Microelectromechanical Systems

The MEMS project team made impressive progress in 2003 in developing new bioelectronics projects in collaboration with the National Institutes of Health (NIH), while continuing good momentum in existing programs of standard test structures, SM3 competence-building initiative, and ATP projects. This team communicates effectively with industry and academia on a routine basis. The team members have been active in society meetings and in attracting visibility to SED in its role in MEMS research for the scientific community. In addition this team continues to support the industry needs for standard test methods for MEMS. It has written and has had accepted by ASTM three test methods for length and strain measurements using optical interferometry and has developed a Web-based round-robin experiment to determine the accuracy and bias of the three test methods. The resulting e-standards will be the first MEMS standard test methods in the United States.

The project on IC interconnects and wire bond test structures developed MEMS structures for measuring the elastic modulus of thin films and stress state during wire bonding. These projects can be very useful for the development of Cu low-k interconnects (with the test structures used for characterization of porous, low-k dielectric films) and for evaluation of the wire bonding process. Although in its initial stage, the collaboration with NIH has good potential to extend the MEMS project into biomedical applications.

The panel is pleased with the MEMS project's broad collaboration with NIST laboratories besides EEEL—for example, the Chemical Science and Technology Laboratory, Physics Laboratory, and Information Technology Laboratory—and a new collaboration with NIH's Instrument Research and Development Division of Bioengineering and Physical Science. The new collaborative effort has added funding and a new NIH postdoctoral researcher who has broadened the technical expertise of the team. With the new competence-building program focusing on bio-MEMS, the project has doubled in personnel and added more than 20 percent in funding.

Thin Film Process Metrology

The Thin Film Process Metrology project offers an important service to the semiconductor industry in providing methodology, optical standards, and properties of dielectric thin films for thickness measurements of gate oxide and high-k dielectric thin films. In 2003, this project continued to make good progress in extending the optical ellipsometry method for thickness measurements of ultrathin dielectric films. The advances included an improvement in ellipsometer alignment and the study of humidity effects for improving the accuracy and reproducibility of ellipsometry measurements. The characterization research has been extended from ellipsometry to include high-resolution TEM and capacitance-voltage measurements to check the agreement of optical measurements with electrical and physical measurements for ultrathin oxides of 2-nm thickness. A Woollam VUV ellipsometer has been installed and is being tested. This instrument will extend the optical measurement to the 0.75- to 8.5-eV range, making it possible to measure high-k dielectrics with band gap usually in the 5.5- to 6-eV range.

The continuing advance of the CMOS technology presents significant challenges to this project, pushing the limit of optical techniques for thickness measurements of gate dielectrics to the nanometer range. The implementation of high-k gate dielectrics requires accurate optical standards and a database for calibration of thickness measurements. The development of new device structures, such as quantum dots and silicon on insulator (SOI), provides additional research opportunities. These are focal areas of this project for 2003, and the panel found them to be timely and relevant to the industry. The panel is particularly interested in further development for the calibration of optical thickness measurements using complementary TEM, electrical and electron spectroscopy methods for graded interfaces, and stacked structures in the nanometer thickness range.

Nanoelectronic Device Metrology

The Nanoelectronic Device Metrology project aims to investigate and develop metrology for two post-CMOS technologies in two related tasks: (1) the Molecular Electronics task and (2) the Si-based Nanoelectronics task. The premise is that the industry for emerging nanoelectronic devices will require reference data, standards, measurement protocols, and standardized test structures as well as associated measurement protocols to develop these devices into a viable commercial technology.

Although the program is only a little over a year old, there has been significant progress in building up the infrastructure, including the recruitment of team members, formation of research alliances within NIST as well as externally, the acquisition as well as installation of several pieces of major processing equipment, and the development and improvement of device processing capabilities. This infrastructure buildup will undoubtedly help to accelerate research progress in the next few years.

There have also been some tangible results of significance in both tasks, including the development of fabrication processes for a variety of molecular electronic test structures, the successful electrical characterization of these test structures, the design and fabrication of mask sets for Si-based single-electron transistors, and the characterization of Si-based quantum dots.

The panel is pleased to see a forward-looking project such as this one taking root in SED and looks forward to its future success.

Office of Microelectronics Programs

The Office of Microelectronics Programs continues to successfully initiate and manage a broad portfolio of NIST programs in support of the semiconductor industry. OMP provides substantial funding to NIST overall and to SED. It also brings in additional funding, enhances crosscutting efforts across the NIST laboratories, and ensures relevance to needs defined in industry roadmaps—for example, the International Technology Roadmap for Semiconductors. OMP continues to expand its contacts within industry, industry groups, and now, internationally. Specifically, this past year it expanded its linkages to the Semiconductor Equipment and Materials International standards bodies and to IMEC (International Market Expansion Corporation, a major European consortium chartered to advance semiconductor manufacturing technology). OMP continues to facilitate the external visibility of NIST programs and results to customers and provides dissemination resources.

Program Relevance and Effectiveness

Overall, the Semiconductor Electronics Division, through its in-depth knowledge of semiconductor measurement needs and its excellent strategic planning process—which continues to improve each year—has engaged in key programs that have immediate and longer-term benefit to the semiconductor industry. This includes two long-range competence-building basic research projects, SM3 and Molecular Electronics. These efforts are expected to result in the addition of new capabilities and to enable NIST to be prepared for the key developments that are expected to occur in these areas.

The Critical Dimension Metrology effort continues to result in improvement in fundamental CD measurement standard technology that will ideally lead to the delivery in FY 2003 of a successful standard to the industry that meets ITRS roadmap requirements. Plans are in place to transfer this technology to a commercial supplier, VLSI Standards, to free SED from long-term manufacturing needs. Similarly the two- and three-dimensional dopant profiling effort using scanning capacitance microscopy has resulted in a capability that, while not meeting roadmap requirements completely, provides the most advanced state-of-the-art capability in this area. And new breakthroughs continue to be made that show a potential path for fully meeting roadmap needs in this critical area.

The Advanced MOS Device Reliability and Characterization project has successfully kept pace with mainstream ITRS roadmap requirements for silicon dioxide measurements, silicon dioxide still being the only gate dielectric in high-volume manufacturing for the near term and the midrange future. Research efforts continue to provide fundamental understanding and physical models for understanding silicon dioxide failure mechanisms. The success of this project's methodologies and its ability to provide standards for the entire U.S. industry is attested to by the fact that the same standards are now being adopted internationally and are being used in the qualification of offshore foundries.

The Power Semiconductor Device and Thermal Metrology project continues to lead industry needs by providing state-of-the-art capability for the measurement of unique power device characteristics at critical operating conditions. Cooperation with DARPA has led to this team taking a key leadership role in the DARPA-driven Power Device Evaluation Team, which includes national laboratory, industry, and university participants. The team has used a combination of its various skills to develop and characterize a state-of-the-art ultrasensitive gas sensor capability for homeland security. The device is relatively inexpensive, using NIST MEMS and off-the-shelf CMOS SOC fabrication technologies.

The Thin Film Metrology effort has provided valuable state-of-the art characterization and measurement capabilities for new candidate dielectric materials and is successfully transferring these capabilities to industry.

The panel continues to see significant broadening in the scope of the MEMS-related projects, now extending into biological or bio-MEMS areas. This effort, in collaboration with the efforts of other NIST groups, has resulted in the funding of the new competence-building SM3 project that is now under way. Also, new funding and participation from the National Institutes of Health have been received. The efforts are timely, given the emerging applications of semiconductor electronics in these areas, the huge surge of activity in mapping the human genome, and the potential applicability in homeland security applications.

The panel is pleased to see continued progress in the development of unique spectroscopic methods that are being used to study novel compound semiconductor device structures. The new state-of-the-art capability for contactless electromodulation and surface photo-voltage spectroscopy is very useful and relevant to research and industry needs.

The Nanoelectronic Device Metrology project improved its process and equipment infrastructure necessary to produce METS this year; it purchased a reactive ion etching and developed various fabrication processes, including metal deposition at low temperature. The project characterized a variety of NIST and non-NIST molecular electronic test structures, including those produced by Hewlett Packard.

Division Resources

The Semiconductor Electronics Division continues to make excellent use of its available resources by collaborations within and external to NIST and by the use of customer or partner facilities—for example, in the use of SEMATECH CD measurement capability for support of the Critical Dimension Metrology project. The panel commends the division for its successful recycling of expensive instrumentation to start up new spectroscopic methods for studying compound semiconductor device structures. Existing clean-room capabilities continue to improve—for example, successful polysilicon gated metal-oxide semiconductor field effect transistors are now being made in the SED clean room in support of the oxide-quality project.

Senior staff turnover in SED is expected to be high over the next 3 to 5 years due to retirements, potentially resulting in the loss of valuable expertise and management skills. The ongoing flat budgets and resulting capital versus staff trade-offs continue to result in compromised strategic planning. Project priorities are strongly influenced by funding and resource constraints.

The nonincremental changes in the semiconductor infrastructure require nonincremental changes in resources that are available to this division and to the Office of Microelectronics Programs. The planned AML, with clean-room capability that is to be shared by all NIST laboratories, is believed to be essential to support the exacting future metrology needs that have been identified by the semiconductor and other nanotechnology industries. The AML will present a key opportunity to add new state-of-the-art measurement tools and other infrastructure required to support NIST's mission in support of industry. The AML clean room facilities will provide an essential resource for the maintenance of SED's relevance to its customer base.

There has been major progress this year in the development of an overall clean-room utilization plan and associated capital equipment list. The plan that has been accepted across the NIST laboratories is a major accomplishment. The panel remains concerned that operational costs for this facility may not be fully understood and at this time are not funded. Also, the level of capital funding that appears to be in the FY 2003 and FY 2004 budget is not adequate for start-up. The Semiconductor Industry Association (SIA) has asked Congress for additional funds to support start-up of the clean room, which may resolve the funding problem; however, this remains to be demonstrated.

RADIO-FREQUENCY TECHNOLOGY DIVISION

Technical Merit

The Radio-Frequency Technology Division provides the national metrology base for characterization of the electromagnetic properties of components, materials, systems, and environments throughout the radio spectrum.

The consensus of the panel is that excellent technical progress was observed during this assessment. The division's performance during the past year is the best that the panel has witnessed in recent years. However, the budget constriction projected over the past several years appears to be a reality in FY 2003; continually shrinking budgets year after year have cut the division to the bare bones. Succession planning factored with strategic planning is critical to the division's future.

It was noted by the panel that detailed, division-level strategic planning is not visible in the Radio-Frequency Technology Division. Broad guidelines for strategic planning should be developed at the laboratory level; detailed planning and ownership should take place at the division level. The division should also develop long-range plans based on technology trends and on the need to retain critical legacy systems and competency. These long-range plans should be incorporated in the EEEL budget process to provide adequate personnel, facilities, and equipment resources at all levels.

The division continues to explore new directions for the advancement of wireless technology by proactively supporting the development of standards for broadband wireless access through the program on IEEE Wireless Standards. The division also continues to make progress in aligning its projects with the needs of the telecommunications and wireless markets and with the areas of homeland defense and the metrology associated with RF exposure measurements for the National Institutes of Health. Broad-based strategic planning covering the next 5 years is becoming an increasingly essential undertaking in the NIST budget planning process as well as a tool for prioritizing programs in a changing environment. In this climate, division management has done a commendable job of nurturing new efforts focused on extending the state of the art in the area of RF technology.

The following list of projects that are advancing the state of the art in RF technology demonstrates the high technical merit of the work performed in the division:

- The Nonlinear Device Characterization project has characterized the phase error in the nose-to-nose calibration of sampling down converters. This advance has uncovered a previously ignored fundamental calibration issue that causes a large uncertainty error. Also, a more general, nonlinear definition of scattering parameters was developed, in collaboration with the University of Colorado; it uses a matrix formulation and reduces to the classical definition for linear networks.
- The High-Speed Microelectronics project, in conjunction with the Optoelectronics Division, has built an on-wafer electro-optic sampling system calibrated to 110 GHz. With this system, the researchers have compared waveform measurements performed on the electro-optic samplings system to oscilloscope measurements, and evaluated these comparisons against the nose-to-nose calibration for frequencies to 40 GHz. This system provides fundamental improvements in accuracy. It constitutes a core capability that will be used in other divisions of NIST and will also provide capabilities never before available for calibrating time domain instrumentation to 110 GHz.
- The Power and Voltage Standards project is exploring a fundamentally new approach to microwave power measurements which is based on the fact that the rate at which an atom, in the presence of an RF electromagnetic wave, oscillates between two quantum states is proportional to the field strength. This new approach will provide an alternative to the RF-to-DC thermal equivalence approach that is based on more fundamental quantum principles.
- The Electromagnetic Properties of Materials project has been working very closely with the health care and biotechnology industries to characterize and develop composite phantom materials (materials that emulate the electrical properties of the human body), in order to test metal detectors and to analyze electromagnetic interference with implanted medical devices. Project researchers are also developing a coaxial probe and associated software for in vitro measurements that will support research in the detection of breast cancer.
- Electromagnetic compatibility (EMC) measurements at 1 GHz and above are being advanced by providing useful information to the EMC community for the purpose of developing acceptance criteria and site calibration methods for open-area test sites at frequencies greater than 1 GHz. Work is also under way to aid in the development of standards for the use of nontraditional test facilities, such as reverberation chambers and GTEM (a tool for measuring emissions radiated at frequencies below 1 GHz) cells. This work is beneficial to the International Special Committee on Radio Interference (CISPR) Subcommittee A and ANSI C63. This participation by NIST personnel is to be commended and supported.

- The Metrology for Bioeffects of RF Energy project in support of the National Institutes of Health is conducting research using reverberation chamber technology. Rats are modeled by 0.5-liter water bottles, and the effect of multiple such phantoms on field distribution in reverberation chambers is being investigated. This work should result in a more efficient and repeatable method of evaluating potential health effects of low-level RF fields than that provided by currently available techniques.
- The Antenna Measurement Theory Application project continues to upgrade its antenna metrology capability to meet evolving customer needs. Although the current capability has been extended up to 110 GHz, industry is quickly expanding up to 500 GHz. The technology challenges, lessons learned, and uncertainty analysis developed by NIST will be invaluable as the capabilities and associated metrology push higher and higher in frequency.
- The Time Domain Free Field RF project's field measurements in the new time domain facility provide a unique capability for ultrawideband RF measurements. This facility is the result of state-of-the-art modeling and design work by the division's staff.

Other projects with content directed at state-of-the-art impact, whose status is best described as works in progress (with goals for state-of-the-art contributions noted parenthetically), include these:

- EMC measurements and facilities (reduction to standards of reverberation chamber calibration techniques),
- Standard EM fields and transfer probe standards (reduction to practice of electro-optic probe for simultaneous E, H measurement), and
- A co-conical field generation system for testing small antennas, sensors, and probes from 10 MHz to 45 GHz. This system will be installed for the Air Force during FY 2003.

Program Relevance and Effectiveness

Calibration and standards measurements in the Radio-Frequency Technology Division generally fall within two categories: radio-frequency standards and radio-frequency fields. Discussions of the relevance and effectiveness of these services, by category, are presented in this section. The calibration services continue to provide a variety of core measurement services in power, impedance, voltage, and noise, as well as transfer standards, over the frequency range of 10 kHz to 110 GHz. Because speed and low cost are critical in these calibration services, many of these tests have been automated and optimized to improve measurement throughput.

Power and voltage standards have improved the understanding and uncertainty of 2.4-mm coaxial power detectors through 50 GHz. The direct-comparison power measurements system has greatly increased calibration throughput and allows measurement runs from 50 MHz to 50 GHz in a single measurement pass. The capability to perform 2.92-mm coaxial power measurements has been added to the direct-comparison system.

Scattering parameters are core to many of the measurements provided by NIST. Improvements were made in the one-port calibration techniques to simplify and reduce calibration time. Frequency coverage is now extended to 65 GHz with the 1.85-mm connector. Also, WR-10 and WR-15 s-parameter calibration services are now full band.

Testing of the new 1- to 4-GHz coaxial radiometer (NFRad) and the 30- and 60-MHz radiometer has been completed. These radiometers can make noise-parameter measurements at virtually any frequency, from 1 GHz to 65 GHz as well as 30 and 60 MHz. They are now well positioned to provide noise-figure and noise-parameter measurements over this same frequency range. They also assisted in evaluating the calibration of NASA's conical scan microwave radiometer, resulting in an improved uncertainty analysis as well as design improvements.

Nonlinear measurement and metrology methods remain a critical issue throughout the field of wireless and wire line communication and will have extensions into ultrawideband nonlinear applications. Measurement capability has been extended from 20 GHz to 40 GHz. Suitable methods for comparing the measurement accuracy between different measurement systems have been selected through collaboration with the NIST Statistical Engineering Division. Also, the measurement and characterization of a candidate superconducting device, developed jointly with the Electromagnetic Technology Division as a "standard" nonlinearity, were completed. Collaborations with university and industrial companies continue to ensure alignment with the needs of the customers in this new area. The first step toward a NIST-led measurement comparison for nonlinear circuit characterization was also completed.

In this work, a prototype of a universal testbed for characterizing electrical probes for nanoscale device and interconnect characterization and a frequency-domain method of characterizing high-impedance probes suitable for performing noninvasive on-wafer waveform and signal-integrity measurement were developed. Additionally, an accurate method of measuring the characteristic impedance of a transmission line fabricated on loss silicon substrates was created, and an accurate, on-wafer calibration using this method was implemented. The methods and instrumentation for accurately characterizing small, printed coupled lines and multiline TRL (Thru-Reflect-Line calibration method) on-wafer calibrations were also accomplished.

In response to the microelectronics industry, accurate methods have been developed for measuring the dielectric properties of thin films, extending the frequency capability above 40 GHz, including on-chip measurements. In support of the printed wiring board and the low-temperature co-fired ceramic industries, the laboratory has enhanced its wideband, variable-temperature metrology for measuring the permittivity of ceramic materials commonly used in the electronics industry. Theoretical and experimental research is also being performed in the emerging area of metamaterials. Metamaterials allow for novel electromagnetic behavior owing to their ability to exhibit simultaneous effective negative permittivity and permeability.

NIST is a central contributor to work on understanding and utilizing reverberation chamber technology for EMC testing. At present, such chambers produce results that do not directly correlate to traditional EMC test facilities. NIST is working to provide data to standards writing bodies to aid in the development of new standards that will apply to these chambers.

An increasing concern among the public is the potential for harm from low-level electromagnetic waves from cellular telephones and other devices. Research to date has been inconclusive at best, with many studies showing a lack of understanding of basic RF measurement processes by biological researchers. NIST is providing the National Institutes of Health with expert guidance in the proper measurement of electromagnetic fields to aid in the repeatability of experiments in this area by investigating the use of reverberation chambers for animal (rodent) RF exposure studies.

The commercial EMC community is performing emissions measurements significantly above 1 GHz. Techniques that are adequate for measurements and facility acceptance below 1 GHz become increasingly unreliable and time-consuming as frequencies exceed 1 GHz. Work is under way to investigate alternative test methods and facilities (e.g., reverberation chambers and GTEM cells) to improve the accuracy, repeatability, and speed of testing at these higher frequencies.

In order to meet the ever-increasing demands of government and industry, NIST has recognized the need to expand its frequency coverage for antenna calibrations and services. Special test services to include frequencies from 75 GHz to 110 GHz have been upgraded. However, measurements up to 500

GHz are requested routinely and cannot be performed owing to instrumentation and facility limitations at NIST. Building on a solid planar near-field foundation, NIST has extended its work into the spherical near-field scanning arena and developed a three-dimensional probe position-error correction scheme for spherical near-field scanning applications. This software has been made available to industry; the work is complementary to the planar near-field probe position work previously developed. A spherical near-field scanning computer-processing algorithm has been developed to ameliorate the effects of partial or truncated spherical scan data, which can occur due to blockage or an incomplete measurement set. This work has demonstrated that the improper processing of partial data can result in serious anomalies in the processed far field.

NIST has developed and is currently manufacturing an expanded set of radar cross-section (RCS) calibration artifacts to provide the capability to calibrate systems at various signal levels of interest. There are plans to design and conduct an interlaboratory comparison to assess the results. The goal is to fully assess the technical merit and deficiencies of existing calibration and measurement procedures, data analysis techniques, and uncertainty analysis associated with RCS measurements. NIST has been instrumental in working with DOD and the RCS community to establish calibration and documentation standards.

A near-field standard probe incorporating a loop antenna with double gaps has been designed and is close to completion. The probe provides the capability to measure both electric and magnetic fields simultaneously at very high levels (up to 2,000 V/m). The radio-frequency probe is fundamental to providing electromagnetic interference testing capability in regions close to source antennas and large test objects such as aircraft. This work has been ongoing for several years, with completion anticipated during the first half of calendar year 2003.

The division continues to provide theoretical understanding and tools to the ultrawideband (UWB) community. By characterizing UWB devices, recent work at NIST has provided a vital step in understanding the potential interference effects of UWB radio and other devices on existing radio services such as Global Positioning System (GPS) and airport navigations systems. NIST also developed UWB chamber qualification tools based on time-domain evaluation of site attenuation. This development provides a method to directly assess the absorber performance of fully anechoic chambers called out for testing in draft standards.

The division's RF Fields Group provides vital services to the associated user community. The calibration services include Antenna Gain Measurements, FBI Antenna, OLES Timing Devices, Shielding Effectiveness Measurements, Radiated Emissions, and Immunity Measurements.

NIST develops and evaluates reliable measurement standards, test methods, and services to support the RF and EMC needs of U.S. industry. The uncertainties of EMC and related measurements directly impact the competitiveness of U.S. manufacturers and the reliability of their products. The Radio-Frequency Technology Division's main objectives are to ensure harmony and international recognition of U.S. measurements for trade, to provide physically correct test methods, to provide national calibration services, and to serve as an impartial expert body for resolving measurement inconsistencies. In order to accomplish these goals, the division is actively involved in international and domestic standards activities.

The division disseminates research results by means of archival publications, conference presentations, workshops, courses, and external interactions, including a Web page. It also makes applications software available for downloading from its Web page.

Division Resources

The Radio-Frequency Technology Division has again been significantly affected by the loss of several key personnel owing to serious illnesses and retirement. The panel commends the division for perseverance through these difficult times. The current staff, even with the pressure to do more with less, appears to be highly motivated. Staff members are continually looking for ways to perform their jobs in a more efficient manner, especially in the traditional areas of calibration and characterization.

The panel observes that budgets shrinking year after year create an ever-shrinking workforce. As more and more is asked from a division having to maintain legacy systems and salary increases, personnel who leave cannot be replaced. Succession planning factored with strategic planning is critical to the division's future. This planning must be done before the staff shrinks further, creating a situation in which critical work cannot be continued until new capabilities are developed. The shrinking workforce is starting to impact the division's ability to perform its fundamental functions in supporting industry and national defense.

As stated above, broad guidelines for strategic planning should be developed at the laboratory level, and detailed planning and ownership should take a place at the division level. The division should develop long-range plans based on technology trends. These long-range plans must be incorporated in the EEEL budget process to provide adequate personnel, facilities, and equipment resources to maintain the division's ability to provide critical services. In addition to long-term plans, current processes and procedures should be documented to allow for the smooth training of new personnel in the future.

The panel again deems the current status of Building 24 as marginally functional. Although the condition of the facility has improved, its current state will significantly compromise NIST's ability to perform near-field antenna pattern measurements as they continue to push to higher frequencies (beyond 110 GHz); a prime example is the new Millimeter-Wave Planar Near-Field system. Continuing the development of facilities for higher frequencies will enhance EEEL's understanding of the limitations imposed by the current facility.

Environmental control is a key contributor in the uncertainty analysis of virtually every measurement system in the division. Without the ability to control this environment, the quality of the final product delivered to the customer is significantly degraded, if not compromised. Each of the laboratories must have the ability to control these environmental factors. Attempting to design and maintain an environmentally controlled facility after its construction is very inefficient and expensive. The proposed RF EM-Field Metrology Laboratory (REML) would provide such an environment.

The Radio-Frequency Technology Division has developed a proposal for a new world-class radio-frequency electromagnetics experimental research and measurement standards facility that will enable NIST to carry out its mission to support industry. REML will provide the capability to address a broad range of national and international requirements for precise characterization of free-space and bounded EM fields throughout the radio spectrum. Many of the current facilities are dated and are no longer adequate to address emerging commercial and international measurement needs. Owing to the pervasive use of wireless communications and other emerging electronic technologies, the world electromagnetic environment is becoming increasingly dense and more complex. As a result, the performance of measurements and calibrations outdoors is becoming problematic. This problem has led other countries to invest in developing the next-generation electromagnetically shielded indoor measurement, research, and calibration facility.

The Boulder EM measurement facilities would have been adversely affected when the high-definition television (HDTV) networks became operational over the next several years, owing to the laboratory's proximity to possible transmitter locations. However, as a result of the diligent efforts of the division chief, these transmitting antennas have been moved to a location farther away from the laboratory, preserving the ability of the laboratory to continue its work. In spite of this success, the panel suggests that a formal architectural and engineering study of the proposed REML facility be performed. The new facility will consolidate the electromagnetic field activity (laboratories and personnel) under one roof, which will foster increased intradivision interaction and collaboration and will increase efficiency in meeting customer and internal research needs. REML is critical to the future success of the division. The short-term plans for enhancing the existing laboratories will result in more resistance to developing REML—"there is nothing more permanent than a temporary situation." In addition to the REML facility, strong consideration should be given to building a new open-area test site (OATS) facility at the nearby national radio quiet zone.

ELECTROMAGNETIC TECHNOLOGY DIVISION

Technical Merit

The Electromagnetic Technology Division creates, develops, and promulgates state-of-the-art measurement capabilities and standards using quantum phenomena, low noise available at cryogenic temperatures, and fabrication of specialized integrated circuits, including nanometer-size devices. The division does not focus on a single industry, but rather sees its overall mission as unique standards development for various electrically based industries. The division balances its mission to industry, government, and scientific organizations with programs that are directed to more fundamental work that can potentially lead to new standards.

The Electromagnetic Technology Division is divided into four projects: the Quantum Voltage project, Cryogenic Sensors project, Quantum Information and Terahertz Technology project, and Nanoscale Cryoelectronics project. There is no group-level organizational structure in this division. The technical merit of each project is addressed in the following discussions.

Quantum Voltage

The Quantum Voltage project focuses on the development of new and enhanced AC and DC voltage standards based on superconducting Josephson junctions. Its primary goal is to develop a quantum-mechanically accurate voltage source, both for AC and DC metrology. A Windows-based software package has been developed to update and replace the older, DOS-based software for the conventional 10-V Josephson voltage standard. A programmable 1-V Josephson voltage standard was delivered to the Electricity Division, and continued systems support is being provided. To achieve the necessary higher voltage outputs, arrays have been coupled in series, and nanoscale junction technology and novel multilevel-stacked junctions are being developed. A record level of one-quarter-volt AC has been demonstrated. This system, with an astounding 8,200 Josephson junctions, will be capable of synthesizing arbitrary AC waveforms from DC to about 10 MHz. Comparisons with existing AC voltage standards are under way.

For future AC voltage sources, more compactly packed junctions will be needed, so work has begun on multilayer-stacked junctions, with stacking of up to three junctions already accomplished. The development of the stacked junctions involved a novel fabrication scheme of $MoSi_2$ as the normal metal tunneling barrier; tests with thousands of such junctions have shown the quantized voltage steps. Work continues on the development of state-of-the-art nanometer control of the length of the normal metal barrier. An arbitrary bit stream generator with gigabit memory and with 1-Hz resolution at 10 Gbps is needed for the waveform synthesizer; no such commercial system is available, and the panel commends the project team for its progress in developing a low-cost bit stream generator. A cryoprobe technology needed for commercial use of the 1-V programmable standard was transferred to high-precision devices.

In collaboration with the Quantum Information and Terahertz Technology project, a Josephson arbitrary waveform generator for a quantum Johnson noise thermometer is under development. A quantum voltage noise source has been compared to a resistor by correlating the synthesized waveform with that produced by a resistor. The cross-correlation electronics continue to be improved.

Cryogenic Sensors

The tightly focused Cryogenic Sensors project is based on state-of-the-art optical and X-ray microcalorimeters that employ superconducting transition-edge bolometers as detectors of radiation. The goal of the work is to continue the development of these systems and to apply them to measurements of electromagnetic signals for applications in the semiconductor industry and in astronomy. This program is now quite mature. The basic strategy is to produce user-friendly systems that combine quantum efficient superconducting detectors operated at low temperatures coupled to efficient room-temperature electronics for processing the data. This ambitious engineering strategy is necessary to make this technology accessible to customers. The progress made on the X-ray microanalysis is impressive in its identification of particle contaminants in semiconductor processing. The technology is now being commercialized worldwide; two U.S. companies have been licensed by NIST to implement the technology.

A key milestone in this project has been the placement of an X-ray microcalorimeter in the Chemical Science and Technology Laboratory at Gaithersburg. This instrument is now in full operation and is achieving unprecedented energy resolution in the microanalysis of thin film and particles. Work at present is focused on comparing the relative merits of optical coupling of the X-ray signal to a single-pixel detector versus direct coupling to a multipixel array. Conventional optics systems continue to suffer from difficulties in alignment, inefficiency at high energy, and low count rate, making quantitative analysis slow and erratic. Replacing the detector with an array can achieve a comparable solid angle with improved count rate and stability. A 32-pixel chip has already been produced and is currently being tested.

The main challenges in advancing bolometric arrays are to develop fabrication schemes for close-packing detectors and to design multiplexing electronics to read out the detectors selectively and quickly. Two attractive approaches to fabricating arrays are being pursued. The first uses deep reactive etching to form a grid of Si_3N_4 membranes that support the transition-edge bolometer; the second constructs suspended bolometer mounts using surface micromachining with XeF_2 gas. At present, 8×8 pixel versions of both methods have been successfully produced and are being evaluated to determine which is the most promising and scalable. Also in progress is the implementation of an improved scheme for the multiplexed readout of these arrays. It is anticipated that this scheme will be scalable up to at least kilopixel arrays. All of the components for the detector arrays are now in place, and implementation of this innovative technology is expected in the next year.

An optical-sensitive version of these arrays is being developed in collaboration with NASA for radio astronomy detection. NIST is a partner in developing an improved camera for the Submillimeter Common-Use Bolometer Array (SCUBA) at the James Clerk Maxwell Telescope. The first implementation of an 8-bit multiplexed linear array has been demonstrated at the Caltech Submillimeter Observatory. This has evolved into a design for two-dimensional arrays with 10^4 elements cooled on a dilution refrigerator for the new detector, called SCUBA-2. So far, single-pixel bolometers of the type to be employed have been demonstrated and characterized.

Several exciting pioneering efforts targeted to future standards opportunities are currently being explored in this project. These include hot-electron superconducting switches for SQUID (superconductor quantum interference device) multiplexing circuits, magnetic calorimeters, and an on-chip refrigerator using quantum tunneling.

Quantum Information and Terahertz Technology

The Quantum Information and Terahertz Technology project merges an ongoing effort in applications of terahertz radiation for advanced measurements with an emerging program in quantum information processing and computation. A new project leader who is a well-known scientist and an experienced administrator has just been hired to head this rapidly growing project.

The project's detection work has two components, imaging and spectroscopy. In the imaging effort, small-scale arrays of fabricated bolometers are being used for the identification of concealed weapons at room temperature, and for astrophysical applications at low temperatures (<300 mK). A milestone in weapons detection was achieved a year ago with the acquisition of a remote image of a handgun, using a scanned single-pixel bolometer. This will be upgraded to a 120-element focal plane array to allow full image acquisition in an estimated 20 s at a distance of 8 m, with obvious applications for law enforcement and in accordance with the Strategic Focus Area on Homeland Security. Since the goal of this system is to provide in situ identification of weapons, a comprehensive study of the terahertz transparency of various clothing and luggage materials has been carried out.

The spectroscopy effort is addressing issues of relevance to both the semiconductor industry and the astrophysical community. A primary goal is to demonstrate terahertz spectroscopy as a diagnostic tool in plasma etching of semiconductors. The approach is to use submillimeter topographic spectroscopy (STS), in which rotational absorption spectra in molecular gases are used to monitor and control plasma-etching processes. This tool, developed in collaboration with the Physics Laboratory, has been shown to be effective for gas species identification and endpoint detection in thin-film etching processes. Present work is focused on developing uncooled bolometers based on VO_x films, which offer a 10 times improvement in sensitivity over currently used Nb sensors. It is expected that a prototype STS system will be implemented on a commercial plasma etcher in the Boulder laboratory during the upcoming year.

Another highly successful effort, in cooperation with NASA, has been the study of antenna-coupled hot-electron bolometers for high-frequency radio astronomy. These devices outperform superconductor-insulator-superconductor (SIS) and Schottky mixers at frequencies above 1 THz. The focus continues to be on antenna and sensor design and on schemes for characterizing receiver performance.

The newest and potentially most exciting area in the project is the emerging effort in quantum computation and quantum information processing, one aspect of which is the development of optical photon detectors for counting single photons. Single-photon counting is essential for verifying secure, encrypted communication via quantum key distribution and is useful for a number of key tests of Bell's inequalities and explorations of linear optical quantum computing. To date, single-photon counting has been achieved using a bolometer array with weak coherent photon sources. It is expected that the efficiency of this scheme can reach 80 percent by the end of 2003.

The second topic of study in quantum information processing and computation is the use of single Josephson junctions as a qubit for quantum computing. The award of a NIST competency grant has substantially boosted this effort in the past year, enabling an expansion that has included the hiring of several new staff members, the acquisition of a new dilution refrigerator system, and the development of new electronics for the experiments. So far, the entanglement of the ground state and first excited state has been demonstrated by probing the Rabi oscillations between these states in the presence of microwave irradiation. Experiments are under way to measure and understand the coherence time in this system in order to assess its potential for quantum logic operations. Already these experiments have led to a new readout design and suggested directions for improving the materials and circuits employed in the qubits. This effort is directly relevant to NIST's Strategic Focus Area on Information Technology and is likely to be a growth area in the next few years.

Nanoscale Cryoelectronics

The Nanoscale Cryoelectronics project develops novel metrological integrated circuits at the nanoscale; measurement and fabrication techniques for thin films of emerging materials; and micromachined structures for unique measurement devices. A prototype of the electron-counting capacitance standard has shown a repeatability of the value of capacitance to 1 part in 10^7. The capacitance is found by pumping electrons using nanoscaled, cryogenic single-electron devices. Modeling of the fundamental physics of these single-electron devices has led to improvements in device performance. The resulting improved accuracy of the standard will be compared to the calculable capacitor in the Electricity Division. Work continues toward determining the range of useful frequencies for which the electron-counting capacitance standard can be used. Superconducting single Cooper-pair pumps promise faster speeds and more counts than the single-electron pumps as a current source. This source is important in enabling the electrical metrology triangle of current, voltage, and resistance. Fundamental limitations due to single-electron poisoning of the Cooper-pair tunneling have been investigated. Electrically driven, single-photon devices rely on the pumping of a single electron and hole into a nanoscaled semiconducting quantum dot. The recombination results in a single photon, which is needed for applications in quantum information. Two fabrication schemes have been developed. Work on the detection of the rotational modes of a single molecule has begun. The modes are detected by coupling the electrical dipole of the rotor to a single-electron detector.

Progress on devices based on single-electron and Cooper-pair devices has been impeded by the lack of available time on the ultralow-temperature dilution refrigerator. After the 2-year delay of delivery of a new refrigerator by the manufacturer, a new dilution refrigerator was constructed in collaboration with the Quantum Information and Terahertz Technology project. This system should be in operation soon.

The microwave metrology of emerging electronic materials focuses on developing microwave characterization techniques and standards for thin films of materials important in future wireless communications and computer applications. High-temperature superconductor thin films are being developed for microwave filters, microwave power limiters, and for Josephson junction mixers in the terahertz range. The project has participated in the formation of international standards for surface resistance of high-temperature superconductors and in the calibration of nonlinear phase noise. Thin films of ferroelectrics are being studied as tunable dielectric capacitors for use in devices at microwave frequencies. The microwave losses and dispersion have been measured. Microelectromechanical structures enable unique measurement devices and systems, ranging from ion traps to cryogenic sensor array systems.

Program Relevance and Effectiveness

The customers for the Quantum Voltage project are the U.S. electronics instrumentation industry, the domestic and international standards community, and the U.S. military. Support continues to be provided to industries involved in the commercialization of the DC programmable voltage standard; the support includes updated software, improved electronics, and the cryoprobe that was transitioned to industry this year. The quantum noise thermometer will improve the metrological precision of electrical instrumentation.

The Cryogenic Sensors project seeks to create unique devices and systems for metrology and instrumentation based on submicron devices and milli-kelvin temperatures. The customers for the microcalorimetric programs include the semiconducting processing community and the chemical standards community (for X-ray microanalysis) and NASA (for imaging arrays). Several initiatives have the potential for new standards and for impact on industrial efforts. The microcalorimeter arrays for X-ray and infrared spectroscopy are very attractive to the semiconductor industry and may become a mainline diagnostic tool for manufacturing. They may also have a dramatic impact on the astronomy community. As noted above, successful implementation of a microcalorimeter in the Chemical Science and Technology Laboratory at Gaithersburg has been made and is working effectively. Commercialization has been slowed by a variety of technology transfer and contractual difficulties, but it is still progressing. As the rapid development of bolometer arrays continues, it is expected that these elements will have broad impact in radio astronomy and other detection applications.

The goal of the Quantum Information and Terahertz Technology project is to develop sensors in the millimeter-wave and near-infrared regime with improved accuracy, speed, sensitivity, and functionality. Customers include the standards laboratories (in the area of radiometry and thermometry), NASA (for infrared astronomy), and DOD contractors. The newly formed effort in quantum information science is relevant to national interests in security, communications, and computing.

The impact of this project is broad and diverse. It is serving the Office of Law Enforcement Standards, the Department of Justice, and the law enforcement community through the development of a 100-GHz, concealed weapons detection system, which could make concealed weapons detection much less obtrusive and more widely used, thereby saving lives and reducing confrontations. This is just one of many efforts within the Electromagnetic Technology Division that could benefit the emerging homeland security aspect of the NIST program, and it represents a unique opportunity for EEEL to promote a part of the program that can be understood and appreciated by the general public, a key step to obtaining additional government funding. Another major success has been the semiconductor tomographic spectroscopy program, which could help with the characterization of plasma-based semiconductor manufacturing tools, resulting in high yield and greater cost-effectiveness.

The Nanoscale Cryoelectronics project impacts most of the projects in this division as well as others, through its unique electronic standards and its maintaining of the microfabrication facility. The completion of the quantum metrology triangle with the single-electron counting capacitor will be important for fundamental science and metrology. The single-electron counting capacitor will support electronic instrumentation industries by providing a portable capacitance standard. The single-photon devices are important for quantum encryption and quantum computing projects in this division and for other such efforts worldwide. The superconducting current limiter is being developed for the Office of Naval Research to protect superconducting microwave systems that are important in telecommunications.

The microfabrication facility is an important infrastructure to many users in this division and others. Single-electronic devices, microcalorimeters, superconducting qubits, the voltage standard, and most of the other devices in this division are fabricated in this facility. Micromachined ion traps have been fabricated in conjunction with the Physics Laboratory's Time and Frequency Division for applications of the atomic clock and quantum computing. Surface micromachined structures for thermally isolating cryogenic detector arrays have been developed in collaboration with the Cryogenic Sensors project.

Division Resources

The remodeling of several of the division's large laboratories is nearly complete. However, there is still frustration among the staff that the age of the building itself hinders effective climate control. The temperature in some of the laboratories can vary greatly during the day in the summer. The core standards work on the Josephson voltage standard and the electron counting standard capacitor needs more support from EEEL. It is only by outside-agency funding that these programs can maintain their standards work. The reduction of their budgets each year by EEEL tends to send the wrong message to staff members, who are doing outstanding and innovative research and development on core standards for NIST.

The relationship between the newly appointed NIST fellow and the division needs clarification, especially with respect to staff responsibilities, office space, laboratory space, and personnel development and reviews as well as overall division projects and plans.

A new program in the quantum Hall effect is being considered. This program would involve the growth of high-quality GaAs heterostructures for studying the physics and standards application of the quantum Hall effect for a resistive standard. If successful, the growth capabilities would also allow the division to be a supplier of high-quality samples to other divisions and other groups nationwide. At present there is no facility in NIST for the growth of such materials for resistance standards. The study of the quantum Hall effect would be linked to the superconducting fabrication and device efforts; this synergy would provide a unique opportunity for developing both voltage and capacitance and resistance metrology on the same chip. This is a high-risk but potentially very high payoff project.

OPTOELECTRONICS DIVISION

Technical Merit

The Optoelectronics Division provides the optoelectronics industry, its suppliers, and its customers with comprehensive and technically advanced measurement capabilities, standards, and traceability to those standards. The division is divided into three groups: Optoelectronic Manufacturing, Sources and Detectors, and Optical Fiber and Components. The groups are subdivided into various topic areas, including Continuous Wave Laser Radiometry, Pulsed-Laser Radiometry, High-Speed Optoelectronic Measurements, Interferometry and Polarimetry, Spectral and Nonlinear Properties of Optical Fiber and Components, Semiconductor Growth and Devices, Optoelectronic Materials Metrology, and Nanostructure Fabrication and Metrology.

The division staff is broadly talented and experienced and is doing world-class research. The researchers are recognized throughout the field for their technical leadership and their calibration services. Besides the unquestioned relevance of their work to the support of the optoelectronics industry, they have also been extremely responsive to applying their talents and techniques to the issue of homeland security.

The technical merit of the projects in the Optoelectronics Division is extremely high, and the panel commends the staff for the quality of its work. In many areas, researchers in this division are the world-recognized experts in their field, in addition to supplying the world's best calibration services. They produce a large number of important Standard Reference Materials (SRMs) and are supporting additional NIST-traceable services to the industry through novel measurement assurance programs (MAPs) and through source and detector calibration services. The division has done an excellent job of disseminating its work through conference presentations, especially including many invited talks and journal articles. Additionally, there is a greater effort to regularly update an existing Web site that presents highlights of division work and supports publication downloads. The division continues to participate in standards bodies and literally to set the standard for quality in the optoelectronics industry.

Overall, the division has made great progress over the past year, met the milestones highlighted in its overview document, and made significant progress toward its longer-term goals. The Optoelectronics Division has been extremely responsive to the recommendations from the FY 2002 assessment. Some examples include the increased calibration services for higher-power fiber-coupled power meters. The panel had recommended extending the capability to 0.5 W to support the developing industry sector for Raman amplifiers and Raman pump lasers. The division now supports this high-power calibration. In addition, the panel had recommended that the high-speed photodetector calibration services be extended from 65 GHz to 110 GHz. The division has extended its calibration services to 110 GHz and in addition supports both amplitude and phase measurements. The panel had recommended increased research and outreach in the area of polarization mode dispersion measurement and emulation. Researchers from the division have greatly increased their visibility into and reputation in the field by attending special symposia and leading industry workshops in this important field of study. The panel had encouraged a wider dissemination of results, and a Web site has been set up to serve this purpose.

Highlights indicating the technical merit of the division's accomplishments during the 2003 assessment period are presented by group in the following discussions.

Optoelectronic Manufacturing

The Optoelectronic Manufacturing Group develops measurement methods and provides data to support the efficient manufacture of optoelectronic devices and for fabricating advanced devices to support metrology research. Maintaining the level of excellence in the U.S. optoelectronics industry is critical during this economic downturn; the entity that maintains its capability, history has shown, will benefit most when the upturn comes. Partially owing to consistent government support, including that from NIST, the United States remains the world's leading manufacturer of optical communications components and systems for the large and still growing fiber optic communications industry. This unfortunately is not true for the semiconductor and wireless communications industries.

In the area of measurement methodology, impressive capabilities to determine source gas purity have been demonstrated. This work on gas purity is very relevant, and the extremely sensitive in situ measurements, down to 20 ppb for oxygen, will be helpful to both the semiconductor and optoelectronics industries. Improved control of impurities in source gases is expected to increase wafer yields and to allow better control of semiconductor device characteristics. The Optoelectronic Manufacturing Group has been able to correlate phosphine purity with incorporated oxygen in molecular beam epitaxy (MBE) growth. Future work will highlight correlating gas purity with device performance and will also focus on determining concentrations of additional impurities in additional source gases. The base ringdown optical sensing technology developed for these MBE source gas characterizations should also have application in sensing poison gas and biohazards in the areas of homeland security and defense.

There are a number of excellent advances in the area of device development for new metrology applications. Recent results highlighted measurements of ensembles of quantum dots as well as the demonstration of a single-photon turnstile. The ability to generate a single photon, on demand, should allow for new and fundamental advances in optical metrology and in secure communications applications such as quantum cryptography. In addition to the single-photon turnstile, photonic crystal devices are being developed to help control or capture the single photons generated by the turnstile. These photonic crystals will also be used to understand metrology issues associated with photonic band gap materials and devices. The work on nanotechnology should be expanded because of both its relevance to the new technology thrusts of the fiber communications industry and its importance to fundamental advances in metrology.

Advances in the area of nanotechnology have been supported by a competence award and should continue to be supported at a high funding level.

Sources and Detectors

The Sources and Detectors Group develops standards and measurement methods for characterizing optoelectronic sources and detectors. This group has three subgroups focusing on (1) continuous wave laser radiometry, (2) pulsed-laser radiometry, and (3) high-speed measurements. The group continues to provide valuable calibration services for both the semiconductor and the telecommunications industries. Since fees for calibration services are now allowed, these services provide an important funding base in a climate of fixed STRS/OMP funding levels.

Over the past year, the Sources and Detectors Group has improved its laboratory facilities, forged stronger ties with industry (as evidenced by the increase in calibration services of 11 percent), and developed measurement and calibration services that are the world's best and NIST-traceable. Owing to the growth in the electronics industry, this group could potentially continue to increase its interaction with industry by performing calibration services for foreign industries. In addition, as the semiconductor industry continues to evolve, the group should consider the possibility of adding more wavelength capability focusing on moving toward even shorter wavelengths.

The strong interaction of the Sources and Detectors Group with the optical fiber communications industry should be continued; it is clearly supporting the industry well. The source work has primarily focused on telecommunications wavelengths, providing measurement capability for "relative intensity noise," and recently improved the maximum absolute optical power calibration at the 0.5-W level for semiconductor diode pumps for erbium-doped fiber amplifiers, Raman amplifiers, and distributed Raman amplification pump diodes. The panel believes that the 0.5-W level should be increased owing to the industry's use of novel types of fiber amplifiers that require even higher-power pump lasers. At a minimum, the group should aim for the 1.0-W level for next year.

Detector measurements in the optical fiber communications area have focused on measuring the impulse response of ultrahigh-speed photo detectors. Over the past year, the group has extended the measurable bandwidth from 65 GHz to 110 GHz and also added the vector response to its measurement capability. This capability provides both the magnitude and phase of the frequency response of high-speed detectors. The activity in this area could potentially expand to address new application areas of importance, such as wireless communications, microwave photonics, and test equipment development and calibration. Perhaps an industry tie-in could use NIST expertise to develop standards for the use of electro-optic sampling procedures and measurement methods for contactless wafer-scale testing for the wireless and broadband RF industries.

The Sources and Detectors Group has also worked on developing better trap detectors. New technology is currently under consideration for commercialization by ILX, a manufacturer of semiconductor laser-related products. Finally, the group's work in low-level pulsed radiometry will be critical for the future development of optical methods for homeland security and target identification.

Panel's Recommendations. The panel supports and acknowledges the excellent work performed by the Sources and Detectors Group and makes the following recommendations for the next assessment period:

1. Continue advances in high-speed photodiode calibrations, maintaining magnitude and phase capabilities and expanding the application areas for these high-speed devices and measurement techniques;
2. Expand the dynamic range of existing calibration services, including higher fiber-coupled power measurements; and
3. Develop new wavelength calibration services, especially those at shorter wavelengths, as needed by the lithography community.

Optical Fiber and Components

The Optical Fiber and Components Group seeks to develop measurement methods and to help industry and government laboratories with measurement and calibration needs in the areas of optical fiber and component properties. In particular, this group supports the optical fiber (light wave) communications industry. Despite the depressed state of this industry over the past 2 years, it is widely acknowledged that, looking forward, information technologies and systems will play a major role in driving the economy, improving work efficiencies, and indeed, enabling hitherto unimagined functions and applications. A mainstay of the information era is light-wave communications technology, which enables cost-effective transport and distribution of massive amounts of information. When the economy regains its vigor, light-wave technologies and systems will be in great demand, and innovations and new applications will require ever-more sophisticated measurement techniques and standards. In addition to supporting the optical fiber communications industry, expertise in light-wave technologies developed in this group have immediate and direct application in the area of homeland security.

Polarization-mode dispersion (PMD) is a critical property of optical fibers and components and has been an important area of contributions and accomplishments by the Optical Fiber and Components Group. This group has developed SRMs, providing traceability for first-order PMD measurements, which are now available. Present and future activities on PMD emulation and compensation, narrowband capability for PMD measurement, multiple-reflection effects, and second-order PMD measurement are all important for the development of future optical networks. Equally important is the work on chromatic dispersion. The panel continues to encourage joint endeavors and alliances with the industry and academia in these areas of advancement. For example, a novel technique for measuring modulator chirp developed by this group is potentially the most accurate technique developed to date, and industry input on the necessary accuracy for chirp measurements should be solicited and supported.

The work on wavelength standards has been outstanding and has served well the critical needs of the industry. Various SRMs are now available, and new standards are being developed—for example, the novel hybrid fiber Bragg-grating/molecular-absorption wavelength reference transfer standard. The work on high-accuracy frequency comb and super-continuum noise measurement is in the arena of leading-edge techniques; the panel looks forward to interesting results and encourages collaboration with local expert groups.

Optical performance monitoring without the traditional optoelectronic digital conversion and measurement is an area of intense endeavor in industry. The panel encourages the group to investigate how NIST can contribute to meeting the requirements and to stimulating innovation in this area.

Program Relevance and Effectiveness

The Optoelectronics Division has continued to support the industry through unparalleled calibration services, improving and expanding on the base of services supported. During the past year, the division performed more than 312 calibrations for almost 50 entities, developed a new polarization-dependent loss measurement assurance program, developed the first-ever vector frequency response detector calibration at 110 GHz, and improved existing calibration techniques. Improvements to the division's calibration services included an increased Q-series calorimeter range, linearity measurements for 193-nm detectors, 157-nm calorimeters, increased accuracy of measurements of relative group delay, and higher-power fiber detector calibrations. New material calibrations and measurements include determining the refractive index and birefringence of A1GaN materials, characterizing the optical properties of single self-assembled quantum dots, and using cavity ringdown spectroscopy to measure water concentrations in phosphine.

The quality and direction of the current work in the Optical Fiber and Components Group are world-class, and its accomplishments are critical to the development of the light-wave industry and future optical networks. Its well-noted outreach to the light-wave community (e.g., participation in standards groups, symposia, and conferences) has gained for the members of the group well-earned recognition as leaders in the field. The provision of various SRMs has served the industry well, and continuing work in this area is essential. The panel wonders if innovative means for recovering the development cost of the SRMs could be found in order to support this work. Perhaps the measurement assurance program is a good step in this direction.

In the area of materials characterization, the Optoelectronic Manufacturing Group continues to set the standards for higher-purity materials and better-defined compositions. This work is extremely important in supporting technology developments such as solid-state lasers for lighting, biological agent detection, and data storage. Many industry and academic customers rely on this group not only to perform the most accurate measurements, but also to provide accurate correlations between material parameters such as refractive index and birefringence, for example. In addition, the group helps maintain industry-wide measurement consistency by sponsoring measurement round-robins and by supporting semiconductor composition standards development. The panel is pleased to see the first SRMs for AlGaAs composition becoming available and looks forward to such continuing efforts on InGaN. The panel wonders if measurements of strain and injection-induced refractive index measurements on active components such as VCSELs (vertical cavity surface emitting lasers) might not be better done by industry or academia, since the results are highly dependent on fabrication process and structure.

Finally, the Optoelectronics Division has done an excellent job of expanding its measurement techniques and calibration services to include the support of homeland defense. For example, the cavity ringdown spectroscopy techniques used to measure water concentrations in phosphine may be applied to lethal gas and explosives detection. The single-photon turnstile is expected to support work in the fields of secure communications and computing, most notably, quantum key distribution and quantum computing. Also, the low-level pulsed-laser radiometry services supply the armed services with calibrated systems for military applications.

Division Resources

The Optoelectronics Division stands out as unique when compared with other divisions within EEEL, because it is tasked with supporting the most rapidly developing and most highly diversified industrial base, the optical networking and telecommunications industry. This task offers great opportunities for excellent work, but it also presents challenges for balancing research and services. Supporting a growing number of evolving services while generating the new measurement techniques and standards that this dynamic industry demands is difficult, especially in an environment of flat or shrinking budgets. However, the panel believes that the team within the division is up to the task. The panel encourages EEEL to provide as much additional support to the Optoelectronics Division as possible, so that riskier and newer research projects may be pursued alongside continued innovations in more traditional research projects and services.

Funding limitations will restrict the scope of the programs that can be supported by the division. As a result, an aggressive review of priorities and mission areas must be regularly undertaken. The division has been proactive in supplementing its budget with outside funds, but the panel believes that more base funding could be directed to this division, especially for supporting the newer and higher-risk research areas that may develop into important industry standards on a relatively short timescale. It seems reasonable that some of these new topic areas could be supported by nonbase funding, but it is also necessary for some base funding to be available for shorter-term, discretionary project development.

While some progress has been made toward improving facilities, deficiencies continue to hamper work in the division. Upgrades and consolidation of division research areas are long overdue and should be further implemented. A highlight of the past year was the establishment of a newly renovated laser calibration laboratory. By simply moving to a new laboratory space, measurement noise was reduced by a factor of two, and calibration accuracy was therefore increased.

The panel is also concerned that travel restrictions might sever the division's ties with industry. The panel is highly supportive of the outreach that the division achieves by attending conferences, giving presentations and tutorials, and organizing and attending workshops and standards meetings. The success and the impact of the work in this division on the optoelectronics industry depend on travel to industry events, and every effort should be made to ensure that these activities are supported at some level.

Despite the funding challenges, the Optoelectronics Division is providing relevant and high-quality support of measurement techniques, services, and standards to the optoelectronics industry. The panel commends the division for delivering on the priorities and goals set out last year and for leveraging expertise throughout the laboratory to produce the highest-quality results. The division has done an excellent job of balancing research and services, and the staff has been proactive in applying its knowledge and techniques to the concerns of homeland security and defense. The panel encourages the division to be as nimble as possible in supporting new research and measurement areas in order to try to keep ahead of the quickly developing industry. At the same time, it encourages the division to maintain its reputation for technical excellence and to continue to support the services relied upon by the optoelectronics industry. It will continue to be difficult to set priorities relating to this diverse and ever-growing industry, but the panel believes that the division has the leadership and staff necessary to support this dynamic industry, whose recovery is so important to the future economic success of the country.

MAGNETIC TECHNOLOGY DIVISION

Technical Merit

The Magnetic Technology Division's (MTD's) mission statement remains unchanged from last year: "To strengthen the U.S. economy and improve the quality of life by providing measurement science and technology primarily for the magnetic technology and superconductor industries." In last year's assessment, the panel recommended that the mission statement be changed to reflect the division's commitment to standards. This recommendation stands, for the panel believes that although reference to standards is contained in the expressions of the vision and goals of the division, the mission statement has a higher visibility and gives a unifying direction to standards activity. Once again, this panel recommends modification of the division's mission statement to include the word and concept of "standards" explicitly.

The MTD consists of two groups—Superconductivity and Magnetics—which are divided, respectively, into two projects (Standards for Superconductor Characterization and Superconductor Electromagnetic Measurements) and four projects (Nanoprobe Imaging, Magnetic Recording Measurements, Magnetodynamics, and Magnetic Thin Films and Devices). The MTD leadership has undertaken a review of current work and potential areas for growth in the division and is developing a strategic plan that could include reorganization of staff. To this end, a dialogue between management and staff members has produced a list of areas worthy of consideration for future projects. The challenge is to select from this list the areas within the capabilities and charter of the MTD that are most relevant to the needs of the customers and are consistent with the available resources. Discussions with the leadership suggest a vision for making these decisions, although details of new program emphasis and direction are still in flux.

In addition, MTD leadership has looked into a strategic plan for the division, which includes a possible restructuring of the groups along different programmatic lines. The need for additional group leadership is recognized. The panel supports the concept that projects be organized more flexibly, not just with each permanent staff member being a project leader. Giving people the chance to work on several projects as team members and leaders will facilitate the growth and broadening of the staff's skills, will help lessen the feeling that one's future is tied to just one project, and will allow for flexibility in staffing new projects and winding down existing projects. The panel supports a restructuring with these objectives.

It also appears that the Superconductivity and the Magnetics Groups are growing farther apart. Some attempt to build bridges between them is desirable. The proposed changes mentioned above should help facilitate this interaction. Additionally, the panel has identified several specific areas of potential collaboration between the two groups, including ballistic magnetoresistance (already identified within the division), miniaturized mechanical testing of superconductors using MEMS, the applying of the mechanical expertise in the superconductivity area to look into magnetostrictive materials, and standards for magnetostrictive materials.

Overall, the panel finds the division to be a very enthusiastic unit with high morale and some good examples of collaboration. Notwithstanding, there are many opportunities for even greater synergy among areas of expertise, such as those mentioned above. The panel also observes that the technical quality and merit of the division's work are very good. In the following subsections, selected projects that exemplify the high technical quality and merit of the division's work are discussed, and the panel's comments are presented.

Standards for Superconductor Characterization

The Standards for Superconductor Characterization project has made considerable progress in the past year on issues important to the superconductor industry. The importance of the project's work and its high performance are well recognized in the community. The project team has acted as a needed measurement arbiter in ways that are valuable for industry. In the case of the need for reliable measurements of residual resistance ratios exceeding 500—a vital need for large-scale superconducting RF cavities—much has been at stake, since only one or two companies worldwide have been able to make sufficiently pure Nb. Last year it was necessary to develop new and more reliable procedures, and the vital arbiter of these tests was NIST. Additionally, the project has helped the small superconducting industry with complex measurements (e.g., AC loss and marginally unstable, high current density wires), as well as providing unique, higher-temperature critical current, voltage-current characteristics that are needed for the very high field, high-stress coils that large fusion projects such as the International Thermonuclear Experimental Reactor (ITER) require. Finally, the project was able to resolve exaggerated claims of conductor performance that were being made under a Small Business Innovation Research award that others, too, thought were bogus. Excellent leadership and representation have been maintained on International Electrotechnical Commission committees. The project leader is nationally recognized as the right person for this position.

Superconductor Electromagnetic Measurements

The Superconductor Electromagnetic Measurements project has unique electromechanical capabilities and is performing strain-related work that others in the United States are not equipped to do. The work done in this project has a worldwide reputation and is important to the Department of Energy's Energy Efficiency and Renewable Energy program and its High Energy Physics program. Additionally, the staff is working on a new book on cryogenic techniques that will be extremely valuable to the research community.

Nanoprobe Imaging

The Nanoprobe Imaging project has continued its work on in situ measurements of ferromagnetic films using MEMS magnetometers. The MEMS magnetometer is currently being tested in an in-house magnetic deposition system. Submonolayer sensitivity has been demonstrated. Results were presented at the Magnetism and Magnetic Materials Conference in November 2002, and there are plans for testing the magnetometer in an industrial setting in FY 2003. This technology is valuable to the entire magnetic industry, including the areas of magnetic storage (disk, tape, MRAM [magnetic random access memory]) sensors, and inductors (communications), and it offers improved capability for process monitoring over traditional methods such as crystal quartz microbalances, resistivity, and others.

The development in conjunction with the RF Technology and Optoelectonics Divisions of the NIST high-frequency "drop in" MEMS probe testbed to test high-frequency probes is needed in this metrology area. The SM3 program has made substantial progress with the construction and testing of a micromachined magnetic trap fluid cell. The ability to sort and store molecules should have wide-ranging applications in chemical and biological industries. This represents an area for dramatic growth, particularly in OA funding, and can leverage the existing MEMS and microfabrication expertise. The role of this area as a strategic growth area for the division should be evaluated during the restructuring of the division. Synergy with the Semiconductor Electronics Division's MEMS activities presents an opportunity to leverage resources.

The MEMS Cs vapor cell for the chip-scale atomic clock is a very neat application of MEMS technology for miniaturizing precise time measurements. This clock should be very useful in the near term for homeland and military security and for wider industrial applications in which small, relatively inexpensive time standards are needed.

Magnetic Recording Measurements

The panel was gratified to see that magnetoresistive arrays for field mapping had been designed and built for nondestructive current measurement and forensic analysis. This application has been used in failure analysis and on-chip metrology in the semiconductor industry, as well as in areas such as relay aging and fault detection. These areas promise increased speed and accuracy of on-chip failure analysis, and this application is an important new direction for this division and its relevance to the semiconductor industry. Furthermore, this work is recognized to have relevance to the area of homeland security as a forensic tool.

Work on the integral superconducting flux-measurement loop for absolute calibration has been dropped owing to fabrication difficulties. However, a new round-robin evaluation for remanent and saturation moment with 20 participants is under way. The panel, however, recommends that the superconductivity flux standard be reexamined for feasibility and be pursued if this examination shows it to be warranted. In situ surface magnetometry is of great interest for characterizing the surfaces of thin magnetic layers, which are very common in data storage and other applications.

Good work was done this year on spin electronics, and this activity continues to grow within the division. Of particular note are the fabrication and characterization of Ag/Fe/Ag/GaAs structures. This work has led to the building of a spin metal-oxide semiconductor field-effect transistor. The panel eagerly awaits further results of this work. It is an emerging field with great potential.

Magnetodynamics

The Magnetodynamics project has built a CryoPIMM (pulsed inductive microwave magnetometer) for operation down to 20 K. Measurements have been made of anisotropy and damping at temperatures between 20 K and 325 K on NiFe films. A vectorized Bloch-Bloembergen (BB) equation has been used to extract parameters such as the time constant in the Arrhenius-Neel equation. This continues in the same vein as the last few years' work, explaining and fitting the results on primarily NiFe films to phenomenological equations such as Landau-Lifshitz-Gilbert (LLG) and BB.

While the work in this area is authoritative and shows leadership, the panel believes that some new approaches are needed, both in theory and experiment. Along the theory lines, the panel recommends collaborating with theorists who can put the theory on a sound quantum mechanical basis and thus get a better physical interpretation of the results. In particular, it would be useful to examine the role of conduction electron scattering of magnons as the intrinsic damping mechanism in metals and to compare it to established theory. The CryoPIMM should present an opportunity here. Also of interest would be a comparison with micromagnetic models, with a focus on the correct value of alpha to use in micromagnetic calculations.

On the experimental side, the panel has in the past recommended the examination of other materials. Some limited work has been done in this direction, but it should be expanded. Last year the panel asked that the work be extended to smaller-patterned films and to high-coercivity films for media. In response, the group has considered possible modifications to the system that would allow it to reproducibly apply the necessary high fields. The panel urges action on this issue, as medium dynamics is a very difficult measurement problem, with critical implications for the data storage industry. There may be an opportunity for interactions with the Superconductivity Group on the challenge of developing adequate fields. On the smaller-patterned films, the higher sensitivity of the instrument is considered to be an advance. However, to get to the submicron sizes of interest to industries (e.g., recording heads), a thousand-fold increase in instrument sensitivity is likely to be needed. This may necessitate new measurement geometry such as ensembles. The panel would like to know how the higher sensitivity will be used to address the problem. The use of PIMM by several universities (the University of Alabama, University of California, San Diego, and Stanford University) and industries (Nonvolatile Electronics, Seagate) offers examples of important technology transfer.

The new instrumentation and measurements of spin polarization in semiconductors by use of optical pumping and the Kerr effect should prove a useful tool in the development of spin electronics. The work on spin momentum transfer is also very useful to industries such as magnetic recording and MRAM. The measurements of spin transfer efficiency in several useful metals and alloys are cited as very useful to researchers and technologies.

Magnetic Thin Films and Devices

The work being done by the Magnetic Thin Films and Devices project concerning noise characterization in spin valves is very relevant to the sensor and magnetic recording industry. Although today's preamplifiers filter out the high-frequency components of noise, much insight into the physics of these sensors can be gained from an examination of the high-frequency spectra. In addition, as data rates increase, the high-frequency noise will be more important. The panel commends the work already done and notes that real commercial recording heads were used, as suggested in last year's report. The panel also supports the continuation of this work on current-perpendicular-to-the-plane multilayers where new noise mechanisms can be studied. The new work on nanomagnets has potential use in nanoscale memory and devices. Measurement of magnetic and transport properties will help assess the potential of these materials. An aggressive effort to increase the blocking temperatures of these materials is recommended.

Program Relevance and Effectiveness

The panel finds that the programs of the Magnetic Technology Division are relevant to the needs of industry and various government agencies. Responses to comments in last year's report have positively addressed many of the issues raised by the reviewing panel. Items that will need more work and clarification are reorganization, staffing, facilities, and earlier recommendations regarding examination of high-coercivity materials and collaborations with theorists. The superconductor work is well aimed at the U.S. superconductor industry and its big-project customers in the DOE laboratories. This success is exemplified by the strong external funding that the mechanical property work attracts and the wide approval given to the standards work that is being led in the United States from this division.

One of the main goals of the division is the dissemination of standards to industry. This goal is particularly important in the data storage industry, but also with regard to other areas such as MRAM, sensor technology, and so on. The panel was disappointed that the superconducting flux standard did not prove to be technically feasible. It was, however, happy with the magnetic moment round-robin led by the division. Standards are also needed for magnetostriction, magnetic imaging, and so on. Standards based on quantum mechanics would be a good long-range focus for the group. Such standards would enable a substantial increase in the accuracy of the fundamental magnetic standards. This staff has members who participated on committees of ASTM, IEEE, and the National Electronics Manufacturing Initiative (NEMI) (magnetics) and several working groups of IEC TC-90 (superconductivity).

The MTD has partnered or collaborated with, or had an impact on, several universities, government laboratories and agencies, and organizations within the industrial sector. In 2002, the MTD Web site was established, and new links were added. About 100 visits to this site are observed each month. The division has published numerous, quality technical articles in refereed journals. Many good publications with sizable impact on the technical community were produced in the MTD this year, including two book chapters and several invited papers. Division members regularly chair sessions of conferences such as the Magnetism and Magnetic Materials Conference and the Applied Superconductivity Conference and serve on conference committees or act as session chairs of meetings of technical societies such as the IEEE, the American Vacuum Society, and the American Physical Society.

In the area of advanced measurement methods, the division has done excellent work that is highly relevant to industry, government, and the general scientific and engineering communities. Areas relevant to industry include MEMS magnetometers, PIMM collaboration and measurements, probe microscopy, magnetic field mapping, standards, magnetic device dynamics and noise measurements, molecular nanomagnets, measurement of spin polarization, residual resistivity ratio measurements, and strain effects in superconductors. Many of these measurements and those under development can be done in situ, with the added advantage of capturing what is happening in a process and responding quickly to any changes. This capability will be very valuable in factories of the future. All of this work features close collaboration between industrial and government partners. Areas of interest to the government include high-speed nanoscale recording systems for forensic analysis of tapes, magnetic field mapping, "spintronics" as a promising new technology, Cs vapor cell for the chip-scale atomic clock, and molecular manipulation as part of the SM3 initiative.

The work under way on future research topics is very impressive. The work on spin-dependent transport in MOSFETs, quantum surface phenomena, spin momentum transfer, atomic-scale transport, and spins in semiconductors represents appropriate extensions of the core skills of the division.

Division Resources

This year the panel recommends further effort to consolidate the MTD's laboratories. They are now spread out over five buildings, and some of the space is borrowed from other groups and may have to be vacated. The division would benefit greatly in collaboration and interaction from being colocated. The incipient renovation of one laboratory is applauded by the panel. The panel urges continued effort in this area with respect to the other laboratories. An effort is being made to accelerate the repayment of the "loans" for the existing equipment. The panel suggests significant upgrades of the division's equipment. In particular, a new deposition system (MBE), an ion mill, and an upgrade of the e-beam facility in the clean room are encouraged. Provisions for steady infrastructure improvements are essential in the equipment budget. The panel recommends a discussion of alternatives to acquiring the needed capabilities, such as buy, fee for service, share, and so on. There are significant challenges to getting large pieces of equipment. Any strategic plan should include needed major equipment acquisitions projecting out for a few years. The division cannot remain at the cutting edge without constant and systematic upgrading of the experimental facilities.

The superconducting effort, though very strong, is also very narrowly focused and is being carried out by two staff members who are both in the later stage of their careers. Transitioning to some younger staff is needed. Restructuring of the division may offer an opportunity to blend and cross-fertilize the Superconductivity and the Magnetics Groups more effectively.

The panel believes that it is important for the MTD to undertake work in spin imaging and spin imaging standards as well as standards based on quantum mechanics. The MEMS area is an opportunity for significant growth, not for the sake of doing MEMS, but as a tool for miniaturization and for increases in the sensitivity of many of the measurements currently being done. More resources should be applied in these areas as well as to the strategic thrusts of NIST in health care, nanotechnology, and homeland security. More funding support is required for these initiatives.

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Manufacturing Engineering Laboratory: Division Reviews

PRECISION ENGINEERING DIVISION

Technical Merit

The Precision Engineering Division (PED) is responsible for the realization and dissemination of the SI unit of length: it conducts R&D in precision-engineered, length-metrology-intensive systems and provides industry-important, length-related measurement, standards, and technology services. PED engages in a diverse set of programs, organized in four groups: Nanoscale Metrology, Surface and Microform Metrology, Engineering Metrology, and Large-Scale Coordinate Metrology. The division also contributes to the Shop Floor as NMI Program.

The work and the array of capabilities represented within PED exhibit high technical merit and quality. The division performs length measurements over 12 orders of magnitude, all at state-of-the-art precision for National Metrology Institutes (NMIs). This range is divided into four overlapping segments, corresponding to the groups mentioned above, each of which has successfully achieved many goals since the review in 2002 and is making significant contributions to the overall success of the division.

The division's staff continues to record its outstanding work in archival publications. Individual staff members have garnered many technical awards and have played leadership roles in major conferences and industry consortia. The technical quality of the measurement work is also quantitatively benchmarked by round-robin measurement activities with other NMIs around the world, with results that reflect well on NIST.

Timely execution is a key component of technical merit and program relevance. Most projects in PED span multiple years. It is evident from its many ongoing projects that PED engages in a significant

NOTE: Chapter 3, "Manufacturing Engineering Laboratory," which presents the laboratory-level review, includes a chart showing the laboratory's organizational structure (Figure 3.1) and a table indicating its sources of funding (Table 3.1).

degree of project planning. However, the following common elements of planning have been absent from presentations to the panel:

- *Roadmaps* that describe PED's opportunities to address future technology needs. Roadmaps should include PED's assessment of industry needs over time and the corresponding PED resources that can be brought to bear. They should also include a projection of benefits to be gained by using the Advanced Measurement Laboratory.
- *Project schedules* that identify key milestones and deliverables on a time line for each project undertaken. Such schedules would be particularly useful in assessing progress on multidisciplinary projects. Each group involved could speak to a common project plan that showed the interdependencies of activities.
- *Trend charts* that plot historical trends of performance (e.g., measurement uncertainty for a particular calibration, SRM sale volume and revenue, services volume and revenue, cycle time, and cost).

This information would help the panel to distinguish cumulative achievement, current progress toward objectives, and future directions on an appropriate timescale. Its absence handicaps the panel's ability to assess PED performance.

The Nanoscale Metrology Group extends dimensional metrology to the submicron scale, providing standards, measurement capability, and measurement uncertainty guidelines for the semiconductor and nanotechnology industries. Its stated goal is to provide to the U.S. microelectronics industry reference measurements, reference standards, and metrology necessary to realize the production goal of 100-nm devices by 2005. This work encompasses SRMs and metrology methods for photomask and wafer critical dimension, pattern placement and overlay metrology, and the development of three-dimensional structures of controlled geometry whose dimensions can be traced directly to the intrinsic crystal lattice. Consistent with its stated goal, the program has been guided by the International Technology Roadmap for Semiconductors (ITRS); however, project plans do not appear to be directed toward the 2005 target date. Members of the group continue to work in close collaboration with the industry consortium, International SEMATECH (ISMT).

During 2002, the Nanoscale Metrology Program consisted of 10 distinct projects organized in two subprograms:

- The Nanometrology Science subprogram is composed of six projects oriented toward the fundamental understanding of dimensional, placement, and overlay metrology. Nanometer-scale SRMs originate in this subprogram.
- The Nanometrology Tooling subprogram is composed of four projects oriented toward the development of advanced metrology tooling and fabrication capability.

These projects demonstrate the breadth and depth of the Nanoscale Metrology Program in addressing current and future nanotechnology manufacturing needs. For the most part, the projects appear well directed, and the staff is highly motivated.

Under the Nanometrology Science subprogram, significant advances in fundamental scanning electron microscopy and optical microscopy continued in 2002. This work has, in close interaction with ISMT, provided critical guidance to metrology efforts in the semiconductor industry. Notable among these are the model-based line width metrology that is finding acceptance among scanning electron microscope manufacturers and the overlay research and tool development that are central to overlay benchmarking and calibration.

Progress on a number of SRMs was reported, including the issuance of the SRM 2800 Traceable Scale Micrometer Standard, calibration and delivery to the Office of Standard Reference Materials of the SRM 2059 Photomask Linewidth Standard, and the first fabrication of the SRM 2120 SEM Magnification and Linewidth Standard. Through work on the AMAG 4 (ISMT Advanced Metrology Advisory Group) benchmarking wafer, a joint ISMT/NIST project, PED researchers have played a significant role in establishing a common artifact for scanning electron microscopy, scatterometry, electrical probe comparisons, and line-edge roughness evaluations. The panel has not received a status report on the two-dimensional mask standard that was to have been issued in the fall of 2002. To assess the value of SRM work, the panel will require data regarding the dissemination and use of prior SRMs, as well as a projection regarding the dissemination and potential use of the new SRMs.

Improvements were reported in the fabrication of nanotips as replacement electron sources for scanning electron microscopes (SEMs). In previous years, significant improvements in SEM resolution have been reported with the use of nanotips, but tip lifetime is a reported drawback. The work has been conducted with the cooperation of Hitachi, a major SEM manufacturer. No roadmap for implementation has been presented, making it difficult for the panel to assess the progress and importance of this work.

Progress in the Atom-Based Artifact project and the Integrated Dimensional and Electrical Metrology (IDEM) project is notable. The Atom-Based Artifact project was able to provide substrates for the Molecular Measuring Machine Program. Work on IDEM toward the fabrication of sub-50-nm quantum devices earned a PED staff member a Department of Commerce Gold Medal in 2002.

The Nanometrology Tooling subprogram continues to pursue several novel approaches to metrology instrumentation. Progress was made on the molecular measuring machine—where 10-nm line writing capability was demonstrated under interferometric control. While calibration services continued with the existing length-scale interferometer (LSI), work was initiated toward the development of a next-generation LSI tool that is critical to the PED calibration mission.

The Surface and Microform Metrology Group works primarily in the measurement of nanometer- to micron-scale surface features, using microscopy or stylus-based instrumentation. The work of this group supports research and development in microelectronics, optics, other manufacturing industries, and homeland security. In the micrometer (and particularly stylus-based) surface metrology areas, metal-cutting industries are the primary customers.

The staff of the Surface and Microform Metrology Group are highly regarded in the technical community, and their work is world-leading. In some cases, however, NIST instrumentation is lagging behind the instrumentation currently available in industrially based laboratories. As a result, the group is most effective in addressing targeted projects that meet specified needs with existing NIST resources. This group has made significant contributions to national and international standardization for surface metrology, including recent editorial activities for the ASME-B46.1 Standard and the development of a section of the upcoming ISO surface texture series of standards. The group's work on standardized bullets and casings, hardness traceability, uncertainty reductions, and calibration of Type-D roughness artifacts has been effectively performed.

The Engineering Metrology Group works to manage and reduce the uncertainty contribution of the traceability of length, location, spacing measurements, and other traditional geometric and dimensional tolerancing (GD&T)-type dimensional controls (e.g., roundness, cylindricity, perpendicularity, and angle). The group also characterizes, evaluates, and improves instruments that measure lengths and coordinates and develops new techniques for measurements from 1 micrometer, as a lower bound, to a meter as a loose upper bound. It also supports the availability of alternate routes, other than the NIST PED, for industry to establish traceability in these regimes, such as NAVLAP laboratories (e.g., the Oak Ridge Y12 Metrology Laboratory and the Starrett Webber Gage Block Laboratory) and other ISO 17025-compliant laboratories, and the group collaborates with other recognized National Metrology Institutes such as the United Kingdom's NPL and Germany's PTB. The group's primary customers are the U.S.-based discrete-parts manufacturing industry and the measurement equipment makers (such as those affiliated with the American Measuring Tools Manufacturing Association).

The Engineering Metrology Group is performing new calibration research at a reasonable level to support the current and anticipated needs of the discrete-parts manufacturing industry and of measurement equipment makers. Its efforts include research in collaboration with NIST Boulder to decrease the uncertainty of laser interferometry for greater capability in length and frequency metrology; research in dilatometry to measure thermal expansion with lower uncertainty and carry the capability to grid two-dimensional expansion; excellent effort in line scale measurement, with continued world-leading capability despite very old equipment and current research to build a new device; cylindricity capability research in collaboration with industry; new laser micrometer methods for the measurement of spherical and cylindrical diameters; and new probing methods primarily for submillimeter feature-measurement on the M48 Moore Special Tool coordinate measuring machine (CMM) and for use in new calibration methodologies (0.5- to 0.1-mm holes).

The Engineering Metrology Group also is continuing to support research and standardization in uncertainty management. It supports the Shop Floor as NMI Program to provide documentation and to educate industrial users on managing uncertainty and endeavors to include levels of confidence in its measurement developments and services across projects. The group is collaborating with international NMIs to compare its results with those of its international colleagues, which represents an excellent validation effort.

The Engineering Metrology Group's high-quality work on developing the traceability of cylindricity measurements is needed by industry. The group should consider including the impact of instrument band pass in determining traceability. Its plan is to use artifacts that are characterized by only one distinct undulations-per-revolution (UPR) frequency. Just as in determining surface finish, a major contributor to errors in measuring roundness results from misunderstood or insufficient band pass in the equipment and/or the measurement technique. The group has demonstrated the capability to use diamond turning to provide artifacts that have 50 or more distinct UPRs with random phasing, making it possible to map out the response of their signal conditioning and filtering so that users know their machines are performing properly and calibrated to national and international procedural standards. Such artifacts are referred to as Type-D artifacts in ISO standards. The group should consider this approach for its Cylindricity Traceability project.

The Large-Scale Coordinate Metrology Group characterizes, evaluates, and improves instruments that measure coordinates at lengths greater than 1 m. Examples of such projects completed this past year are a shipbuilding measurement system and a laser-tracker calibration system pertaining to missile launch from submarines. The group has undertaken a project to investigate ways of precisely measuring propeller dimensions while simultaneously machining the propeller. These sorts of collaborative projects keep NIST at the forefront of large-scale metrology while at the same time providing a boost to industrial productivity. The group is also involved in the development of standards and artifacts for a variety of devices such as laser trackers and targetless scanners. Members of the group have made numerous presentations and hold leadership positions in many professional organizations and standards-setting groups.

Program Relevance and Effectiveness

PED's Nanoscale Metrology Group ensures the relevance and effectiveness of its activities through close collaboration with both industry and industry consortia and engagement in international symposia. The work of the group is well known throughout the semiconductor and MEMs industries and is highly regarded. Collaborations have led not only to new standards but also to the improved performance of commercially available metrology products such as SEMs and optical microscopy tools. While there is no question of the group's competence and leadership in the nanometer metrology realm, coordination was not evident among the projects undertaken to support the stated mission of enabling 100-nm manufacturing in 2005. Given the rapid pace of technology advance in nanometer-scale manufacturing, where industry development activities are already pushing beyond 100 nm, the panel recommends that the Nanoscale Metrology Group reformulate its mission and projects to improve internal coordination.

The Surface and Microform Metrology Group is engaged in several projects that are beneficial both to industry and to other government agencies (e.g., standardized bullets/casings, hardness traceability), and it also appears that the group is moving into areas that will be very valuable to many traditional metrology customers (e.g., software calibration for surface texture and the development of traceable Type-D artifacts). The panel recommends that discerned tendencies to reinvent work that has been attempted or conducted elsewhere be redirected by increased collaboration outside the laboratory, which may shorten development times and improve results for some projects.

The Engineering Metrology Group receives products from the measurement equipment makers for examining and furthering the state of the art in several areas—a demonstration of its collaboration with this customer segment. The group seems to have a clear picture of its area of responsibility and its duties to satisfy customers' needs. The group's level of income from services ($800,000 in calendar years 2001 and 2002) is higher than that of any other group in MEL, making calibration services self-supporting. The group is relied on heavily by customers that use its services, but the cost of NIST calibrations is pushing customers to seek alternative sources of calibration services.

The Engineering Metrology Group reported that about 20 to 30 percent of its calibration tasks were completed on time; the M48 Moore Special Tool CMM was identified as a particular problem area in this regard. Especially in cases in which a missed delivery date has been set by the division, customers can lose faith in the group's ability to deliver its product. The division might consider referring to the Y12 Metrology Laboratory machine(s) those customers who would be satisfied with the capabilities of those machines. The group's equipment will be going down for approximately 6 months for the move into the new AML. During this time, the group plans to rely more heavily on partner laboratories such as Y12 for continued customer support. The panel is concerned that moving complex equipment could cause previously unforeseen sources of uncertainty that could take significant time (months to years) to solve beyond the time needed to bring the equipment back into service. No plan was presented to deal with such contingencies.

Much of the research of the Large-Scale Coordinate Metrology Group is funded at least partially by industrial or defense organizations. Examples of such projects completed this year are a shipbuilding measurement system for the National Shipbuilding Research Program and a laser-tracker calibration system pertaining to missile launch from submarines for the Naval Surface Weapons Center.

The Large-Scale Coordinate Metrology Group's Shop Floor as NMI Program has as its goal the movement of traceable measurements onto the shop floor and away from the national measurement institutes, except when measurements of the highest accuracy are required. To accomplish this goal, the program is developing a suite of documentary standards, guidelines, and reports. Program staff are working to complete a "smart artifact" and a laser-based ball bar calibration system for the benefit of fixed CMM users and manufacturers. To assist in the evaluation of measurement uncertainty, the program has developed a Monte Carlo simulation method that has now been incorporated into a commercially available metrology software product.

Division Resources

Over the past year in PED, the Nanoscale Metrology Group has addressed the equipment needs pointed out in last year's report. In particular, the group has obtained, installed, and begun working with a Nikon 5i two-dimensional pattern placement metrology tool. This capability will be critical to the support of both mask and wafer metrology. Furthermore, the group is reported to be in negotiations to upgrade its Hitachi SEM and to obtain an FEI Co. high-pressure SEM. The group has shown admirable ingenuity in fitting these normally "big-ticket" purchases into its severely constrained budget. In another creative approach to leveraging expensive equipment, the group has participated in a telepresence microscopy program with government research institutes, ISMT, and universities. Telepresence microscopy enables remote access to metrology equipment among all participants. Savings to date in duplicate instrumentation are estimated to be $3 million. PED is planning a staffing increase in the group commensurate with the growing importance of this area. The upgrades to nanometer-scale metrology equipment should address many of the concerns raised in last year's report regarding NIST's ability to support the capital-intensive industries, such as semiconductor manufacturing, with meaningful standards and timely research. It remains to be seen how effectively this equipment will be used. To make a meaningful assessment, the panel needs to see a roadmap of how the Nanoscale Metrology Group plans to address industry needs, including appropriate insertion points for new standards based on the added capability.

Funding continues to be a challenge for the Surface and Microform Metrology Group. Many customers for this area are often unwilling to provide significant funding on a per-project basis. This lack of funding is evident in terms of the age and capabilities of the group's instrumentation as compared with industrially based applications. This difficulty is further complicated by the upcoming move to the AML facility, which will require considerable downtime and setup time.

Because of the Engineering Metrology Group's collaboration with the measurement equipment makers, the equipment is maintained at a level of technology commensurate with that used by its customers. The M48 Moore Special Tool CMM is world-leading, at an error level of 1 μm or less anywhere in its volume. It is used for length traceability and for evaluation of two-dimensional CMM traceability artifacts and other calibrations. The group's gage block calibration capability is world-class, and ongoing research into the effects of deformation and surface finish are maintaining this traceability program at this level.

MANUFACTURING METROLOGY DIVISION

Technical Merit

The goal of the Manufacturing Metrology Division is to fulfill the measurements and standards needs of the United States in mechanical metrology and advanced manufacturing technology by conducting research and development in realizing and disseminating SI mechanical units; developing methods, models, sensors, and data to improve metrology, machines, and processes; providing services in mechanical metrology, machine metrology, process metrology, and sensor integration; and leading in the development of national and international standards. The division is organized in four groups: Mass and Force, Machine Tool Metrology, Manufacturing Process Metrology, and Sensor Development and Application.

The division's goals apply across a broad scope of activities related to manufacturing, posing a challenge to division management to integrate the technical activities of the four groups. Recognizing resource limitations, division management has made a strategic decision to limit its scope to four major programs: Advanced Optics Metrology, Mechanical Metrology, Smart Machine Tools, and Predictive Process Engineering. It also plays a supporting role in the integrated Nanometer-to-Millimeter Manufacturing Technologies Program, the Nanomanufacturing Program, and the Nanoscale Metrology Program. This focusing of scope is likely to improve the potential impact of each program. These programs, and the technical projects within them, are closely tied to the current core competencies of the division.

The division has several technical programs and projects that are well suited to its role, including those in Advanced Optics Metrology, Microforce Competence, Smart Machine Tools, and Mesoscale Machining. The division is also engaged in metrology services, work on international standards, and international measurement comparisons. These efforts continue to meet the expectations of its customers.

The Advanced Optics Metrology Program is well focused on areas of significant need and is of high technical quality. The accomplishments of the XCALIBIR (X-ray Optics Calibration Interferometer) project, which is focused on an area of significant metrology need in semiconductor manufacturing, are impressive. The laboratory capability and technical results are world-class. The program is well connected to the industrial customers that drive development and eagerly implement results. The panel remains concerned about some current assignments of program personnel. The Manufacturing Process Metrology Division leader has assumed leadership of the Advanced Optics Metrology Program, relieving the division's director as the interim manager. However, the key technical leader of the program is not a full-time NIST employee, which exposes the project and program to risk with respect to long-term continuity and progress.

Work on microforce measurements has shown significant progress in the past year. Its impact is significant, the technology challenges have been clearly identified, and a detailed technical plan has been developed. Each year the Microforce project makes significant progress on the technical plan. It is anticipated that this project will establish the reference standard for small-force measurement.

The Smart Machine Tools Program has been well focused on areas of significant need and demonstrates high technical quality, but the rate of progress has slowed. The program has the requisite technical knowledge and contacts, and the division should take control of planning, accelerate the roadmapping effort, and quickly bring the work to completion.

Driven by its commitments to and involvement in international and regional comparisons, the Mechanical Metrology Program is also well focused and continues to make good progress. The Smart and Wireless Sensors project has cleverly applied its technology to homeland security applications. This project is an excellent example of dual-use technology. The sensor and network technologies can be deployed for homeland security as well as being used in manufacturing applications. During the past year, there seems to have been a major emphasis on homeland security within this project; the team should maintain a focus on manufacturing applications in addition to the new security initiative.

The panel is not able to provide a complete assessment of all the division's projects; updates on some projects that had been showcased in previous years were missing or incomplete. An overview was not presented for the Predictive Process Engineering (PPE) Program, although the division did clarify the objectives of the program and the technical contributions of the division. Nonetheless, the panel remains concerned about the complexity of the integration of all the subprojects. The division adopted the panel's recommendation to focus on a demonstration part of the PPE Program. The individual elements of this program will be integrated and applied from design through manufacturing with this test part. This exercise will demonstrate the challenges, opportunities, and technical complexities of the PPE vision. The panel requests a detailed presentation of the experiences and results of this demonstration exercise in the next division review. The demonstration part will be a critical element for tracking the ongoing progress of the projects and the overall program. After completing the demonstration, the division should reevaluate its available technical resources for this program and, if necessary, secure the appropriate expertise to meet the program goals. Some aspects of the PPE Program are in line with NIST's mission—specifically, the activities of model standardization and material property characterization. The panel did not receive updates on projects in the vibration, acoustics, linear motor, and mass calibration technology areas. The panel requests that, in addition to technical highlights, summaries of all division projects be included during future panel reviews.

Program Relevance and Effectiveness

The Manufacturing Metrology Division serves two primary roles. First, it is the nation's reference laboratory for the units of mass, force, vibration, and sound pressure. In this role, the division provides calibration services, develops advanced methods for mechanical metrology, develops national and international standards, and leads efforts with international standards organizations. This role is critical for the nation's manufacturing industry and for distributed international manufacturing and commerce. The division retains world-class capabilities and has state-of-the-art facilities for a number of metrology services. The XCALIBIR and Microforce projects are excellent examples of newly developed, world-class capabilities derived from technical projects.

The second major role of the Manufacturing Metrology Division is to develop technology for manufacturing and mechanical metrology. The customers of this effort include both industrial and governmental communities. The division fulfills this role through its internal projects and by acting as a catalyst or facilitator for collaborative efforts between government, industry, and academia.

The division's work is disseminated through multiple means. Workshops, consortia, and standards committees continue to provide vehicles for disseminating many research results. Workshops are also used to identify customer needs (for example, the Smart Machine Tools Roadmapping Workshop). Many members of the technical staff are speakers at conferences and seminars. The division is also active in producing publications and presentations and in participating on committees of numerous professional societies. These presentations, the issuance of standards, and the division's technical publications all provide evidence that the division is serving its customers, but these indicators alone cannot be used to measure the impact of these results quantitatively. The impact of calibration services can also be determined by considering the number of paying customers using them. The Mass and Force Group, for example, serves individual paying customers directly and is working with an industrial partner in implementing new, higher-resolution mass calibrations. The continued request for division involvement in standards activities (e.g., IEEE 1451, ANSI/ASME standards, and international standards) also indicates the relevance of the division's work.

After several years of concern, the panel now endorses the matrix management structure within the Manufacturing Metrology Division. Based on a detailed review, the panel has a more complete understanding of the structure and its intent. There are still challenges that need to be met to further improve organizational productivity, competence, and morale. Constant and consistent communication by division management, group leaders, and program managers about the objectives and operation of the matrix management system are essential for success. Division management will need to remain vigilant to ensure that the structure does not cause duplication between group leaders and program managers and provides fair representation for the staff. The matrix management approach can be very beneficial for the division, but its implementation should be continually monitored, and it should be modified as necessary to achieve the intended results.

The panel heard little discussion of project selection criteria during the divisional review (this issue was adequately addressed during the laboratory-level panel review). This observation was also made in last year's report, and it should be an area of continual attention in order to ensure relevance in project selection. The panel recommends that each project be clearly connected to both MEL's strategic plan and the division's mission statement.

Division Resources

As of January 2003, staffing for the Manufacturing Metrology Division included 41 full-time permanent positions, of which 36 were for technical professionals. There were also a dozen non-permanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The panel remains concerned about the division's ability to retain talented technical professionals and to recruit equally talented new employees. Several technically strong key personnel have left the division in the past few years. The success of the division's programs relies almost exclusively on the technical competencies of its staff. Division management recognizes this challenge and is taking steps to address the issue. In particular, the strong emphasis on postdoctoral research associates is part of an effort to identify candidates for employment while also sparking their interest in a career at NIST.

The Manufacturing Metrology Division has limited its scope in programs and projects to match its available resources. One specific challenge within the division is the diversity of function and content. A significant portion of division resources are involved in calibration services and in supporting the Mutual Recognition Agreement (MRA) trials. (This agreement was signed in 1999 by the NMIs of the 38 member states of the Metre Convention.) It is difficult to integrate these functions and specialties into the other technical projects within the division. These functions can, if not carefully managed, dilute the overall technical impact of the division. The panel recommends that the division carefully evaluate the tasks assigned to the nontechnical staff.

The Manufacturing Metrology Division has engaged in appropriate, sustained efforts to augment the permanent staff with postdoctoral fellows and guest researchers. The division increased supplemental staffing by 4.8 full-time employees from 2002 to 2003. Division management and staff should take measures to ensure that the experiences of these supplemental employees are positive so that they may favorably consider future employment at NIST.

The division's budget and number of employees have been relatively stable over the past few years. In contrast, many industrial and educational institutions have experienced dramatic reductions in budgets and workforce. The division has also accomplished significant facility improvements. Two new machine tools were acquired in 2002. These assets represent very significant enablers for the technical projects and programs of the division.

The continuing role of the division as a leader in the development of national and international standards ensures that the interests of the United States are protected. For this reason, the division must continue to provide adequate resources in this area. The division devotes significant resources to the key comparisons and other requirements called for in the Mutual Recognition Agreement. The division's continued active role in this area is imperative.

INTELLIGENT SYSTEMS DIVISION

Technical Merit

The goal of the Intelligent Systems Division (ISD) is to develop the measurements and standards infrastructure needed for the application of intelligent systems by manufacturing industries and government agencies. The division is organized in five groups: Perception Systems, Knowledge Systems, Control Systems, Machine Systems, and Systems Integration. These five groups work on the following programs: Intelligent Open Architecture Control of Manufacturing Systems, Intelligent Control of Mobility Systems, and Critical Infrastructure Protection. These three programs are managed by ISD. The division also supports the following MEL programs: Predictive Process Engineering, Smart Machine Tools, and Nanomanufacturing.

Improvements and extensions of the Standards for the Exchange of Product Model Data (STEP) programs are advancing in several areas and involve several of the MEL divisions. The MEL Precision Engineering Division is directly involved with extensions to support assembly, interpart relationships, mating features, and representation of features and tolerances. Interoperability is a key issue, and in the Intelligent Systems Division, the Intelligent Open Architecture Control (IOAC) of Manufacturing Systems Program is addressing important issues in the use of STEP as a basis for the automated generation of process programs and control. STEP-NC (STEP-numerical control) is intended to generate NC programs directly from base computer-aided design (CAD) description. The IOAC of Manufacturing Systems Program has participated in a conformance testing pilot and has contributed to an ISO white paper on this topic. This program should continue to work on these topics. Strong interaction with commercial vendors and machine tool manufacturers involved in NC development is important. A systematic view of the interdisciplinary interactions among MEL divisions and the long-term plans for continued development are strongly encouraged.

The goal of the Intelligent Open Architecture Control of Manufacturing Systems Program is to develop and validate, by 2005, key interface standards and conformance tests for those standards, and to achieve interoperability among control systems for machines on the factory floor and with design and planning systems and factory data networks. The program encompasses work on a number of standards and on testing and validation of standards for several different industries and equipment types. The staff is working with industry groups (such as the Automotive Industry Action Group and Robotic Industries Association [RIA] and Open Modular Architecture Controller [OMAC] user groups) to realize common benefits. For FY 2003, expected outputs include an interoperability demonstration of STEP-NC for milling, testing utilities for I++ dimensional measurement equipment, an OMAC application programming interface, database implementation of American Welding Society (AWS) welding procedures and test results, and an RIA technical report on robot-controlled network configuration. Progress has been made in 2002 toward realizing those goals. ISD has developed a testbed for the evaluation of these requirements and has replaced the Hexapod machine with two commercial machine tools. The division's work platform has become more representative of target commercial platforms.

The goal of the Intelligent Control of Mobility Systems Program is to provide architectures and interface standards, performance test methods and data, and infrastructure technology needed by the U.S. manufacturing industry and government agencies in developing and applying intelligent control technology to mobility systems to reduce cost, improve safety, and save lives. The program consists of elements that focus on DOD unmanned ground vehicles (UGVs), industrial material handling, and performance measures for mobile robots. Accomplishments on DOD UGVs in 2002 included successful demonstrations of NIST real-time control (RTC) controlled robotic vehicles and the publication of a reference model architecture for UGVs. The NIST team, among the world leaders in UGV technology, received the Jacob Rabinow Applied Research Award for its R&D in robotic perception, planning, and control and its application to UGVs.

The Industrial Material Handling project aims by 2005 to provide industries with necessary standards, performance metrics, and infrastructure technology to support the use of noncontact safety sensors and control systems that enable broader use of advanced perception and navigation techniques in the automated guided vehicle industry and other industries. The division is developing an indoor testbed vehicle industry that will support technology integration and testing to study technology transfer to the Industrial Material Handling project from DOD work and from Department of Transportation work on autonomous highway driving and vision-based lane-following. The objectives of the Performance Measures for Mobile Robots project are to provide by 2005 the evaluation and measurement methods, testing procedures, and standard reference data needed for performance analysis and deployment of advanced sensors, and for intelligent vehicle control systems on manned and unmanned vehicles used in next-generation transportation safety systems and in UGVs for the military.

The Competence Development and Infrastructure Program develops fundamental competence in areas of broad relevance to the division. The program's goal is to provide a clearly defined framework within which intelligent systems technologies can be readily evaluated, specified, and integrated by U.S. manufacturing to provide breakthrough levels of productivity. The program defines four principal areas of fundamental research: metrics for intelligent systems, knowledge engineering of models supporting sensory perception and control, architecture and tools for building and integrating intelligent controls for complex systems, and learning methodologies supporting optimization and adaptive control. Significant accomplishments in metrics during the past year have included development of test arenas for rescue robot tasks, performance metrics for human-robot interaction studies, and the Third International Workshop on Performance Metrics for Intelligent Systems. In knowledge engineering, work on model representation, especially moving-object representation, is of particular relevance to the mobile robot programs. In the architectures and tools work, the primary focus continues to be the development of RCS, with publication of the 4D/RCS Reference Architecture and applications to USCAR (United States Council for Automotive Research) and DARPA/MARS (Mobile Autonomous Robot Software) projects. Fundamental work on learning algorithms has focused on planning graphs that incorporate constraints and decision preferences.

Overall, the Competence Development and Infrastructure Program is well conceived and implemented. Significant applied research is being performed, and coordination with other programs integrates this work with the overall efforts at ISD. The staff is capable and includes individuals well known and respected in the wider scientific and academic communities. The mix of senior and junior researchers provides a strong base for future growth. More than 30 publications and a recent Ph.D. dissertation are indicative of the good visibility and external involvement of this program.

Progress in the important areas discussed above is responsive to the recommendations of this panel from last year.

The goal of the Critical Infrastructure Protection Program is to increase the security of computer systems that control production and distribution in critical infrastructure industries—including industrial utilities; processing industries such as oil and gas, chemicals, pharmaceuticals, metals and mining, and pulp and paper; and consumer products and discrete-parts manufacturing industries. The long-term objective of the program is to integrate security engineering into the industrial automation life cycle, including design, implementation, configuration, maintenance, and decommissioning. The outcome should be a reduced likelihood of successful cyberattack on the nation's infrastructure.

ISD has taken the lead in forming the Process Control Security Requirements Forum (PCSRF), with representation from related industries, concerned government and private agencies, and NIST divisions. PCSRF's goal is to increase the security of industrial control systems through the definition and application of a common set of information security requirements for these systems.

The NIST process control testbed is structured to develop and disseminate best security practices and validate security standards for the acquisition, development, and retrofit of industrial control systems. The testbed is well planned and offers a variety of testing opportunities required to realize its objectives. ISD also serves as PCSRF liaison with the Instrumentation, Systems, and Automation Society (ISA) Manufacturing and Control Security SP-99 Committee, with the long-term goal of developing standards to validate the security practices of manufacturing sites.

Program Relevance and Effectiveness

NIST has been a leader in the development of tools and standards to support product representation underlying computer-aided design/computer-aided manufacturing/computer-aided engineering (CAD/CAM/CAE) systems used in product development and manufacturing. The STEP standards have been extensively developed over the past 15 years, and NIST has been a leader in the development of the underlying concepts as well as the dissemination of those technologies to industry. The STEP standards are currently used in several industries, and international standards organizations are moving toward wider adoption. Much of the basic STEP development has matured and is beyond the research horizon of NIST programs.

With the Intelligent Open Architecture Control of Manufacturing Systems Program, ISD can have significant impact on industry through the promulgation of standards for intelligent systems. To achieve relevance, ISD is striving to enroll support from industrial users, NC control suppliers, and industry trade organizations, and it has realized some success. This support is critical for the program to realize its objectives. The program has gained appreciable momentum. Over the last 3 years, its objectives have evolved appropriately to meet realistic expectations in industry. The program team is reaching out to potential customers, primarily production equipment users and some user trade associations. Reaching out to equipment suppliers whose products have to be modified to apply the technology is critical to the success of this program if practically feasible standards are to be realized. These manufacturers can play a unique role in driving future directions of the program and ensuring an opportunity for the integration of new methods into products. Collaboration with other trade associations, such as the Machine Tool Builders Association, is also encouraged.

In terms of expenditure, the Intelligent Control of Mobility Systems (ICMS) Program is the largest program in ISD, but a significant portion of the expenditure on this program was obtained from other agencies (OA). While the strong dependence on OA funding may make the program vulnerable, depending on such funding's stability, ICMS has succeeded in past years in securing such funding. Furthermore, the program plan incorporates long-term support of the Army Research Laboratory's (ARL's) autonomous mobility program at least to FY 2005, and at this stage the NIST ICMS group and ARL appear to be inseparable partners for the foreseeable future. The Industrial Material Handling and the Performance Measures for Mobile Robots Programs help to make the technology developed in the DOD UGV program element relevant to civilian manufacturing problems. ISD is looking into several alternative approaches to increased transfer of the technology of the ICMS Program. Potential new customers such as the United States Postal Service and John Deere's construction equipment division show interest in the NIST ICMS technology. ISD should continue to identify and broaden the customer base of the ICMS technology.

The Competence Development and Infrastructure Program has its closest alignment and influence on the ICMS Program and related externally funded projects. There appear to be opportunities to explore closer linkages to other manufacturing-related ISD and MEL projects that would take advantage of the competence built in the Research and Engineering of Intelligent Systems (REIS) Program. The USCAR stamping project is one example of such linkages; basic modeling and architecture are important to this program. Other examples include more prominent linkage to model-based machine controller projects (asking how learning and adaptive control can be incorporated); a stronger role in projects with the United States Postal Service and related projects in which multivehicle systems will have practical applications; and involvement in critical infrastructure protection, in which the analysis of risk and performance should depend on more detailed models of control, communications, and sensitivity. The strength of ISD continues to be in applied research with effective demonstration and prototype development of direct interest to a wide community of users. The Competence Development and Infrastructure Program supports these commitments through the development of enabling technologies. Improving the breadth of these applications would align the program more closely with its stated goal of integration, enabling U.S. manufacturers to provide breakthrough levels of productivity.

The Critical Infrastructure Protection Program is relevant to the war against terrorism and the need for protection of the nation's infrastructure. Multitudes of customers look to NIST for the development and standardization of critical security elements of their resources.

Division Resources

The replacement of the previous Hexapod machine by the Fryer 4-Axis Lathe and the DMG 5-Axis Machining Center is a very positive step. These new machines are more consistent with equipment currently used in industry, and the acquisition of this equipment will promote collaboration and relevance of the interoperability programs.

MANUFACTURING SYSTEMS INTEGRATION DIVISION

Technical Merit

The Manufacturing Systems Integration Division (MSID) promotes economic growth by working with industry to develop and apply interoperability measurements and standards for software used in all aspects of manufacturing. The division's key objectives are rigorously defined technical data standards and protocols, realistic pilot programs involving vendors and industrial partners, and software and interoperability testing services accessible to small and medium-sized business. The division maintains commercial and research testbeds and engages with appropriate organizations in the standards process to meet these objectives.

The MSID is organized in four groups: Design and Process, Enterprise Systems, Manufacturing Simulation and Modeling, and Manufacturing Standards Metrology.

The technical strategy of MSID is to progress toward self-integrating systems by developing and implementing tactical and strategic projects within the following five programs:

- *Product Engineering*, which includes projects in parametric exchange, design-analysis integration, assembly, tolerance representation, heterogeneous material representation, and knowledge representation, for next-generation CAD systems;

- *Predictive Process Engineering*, which includes projects in process metrology, process representation, process modeling, and process application;
- *Manufacturing Simulation and Visualization*, which includes projects on distributed manufacturing simulation environments, manufacturing simulation transactions, reference data sets, and simulation templates and model formats;
- *Integrated Nano-to-Millimeter Manufacturing Technologies*, which includes projects in atomic-scale measurement manipulation and manufacturing and molecular-scale measurement manipulation and assembly; and
- *Manufacturing Enterprise Integration*, which includes projects on a B2B interoperability testbed and self-integrating systems.

Additional projects are grouped under the rubric of special activities.

The division is engaged in work at several levels of abstraction in system integration capabilities: standards and measurements, process representation, integration, modeling capabilities, and the use of software to enhance manufacturing performance. The programs and projects support the foundational areas of interoperability and metrology (with the exception of the Integrated Nano-to-Millimeter Manufacturing Technologies Program, which supports a strategic, multidivisional focus). The projects are of high quality and are staffed by competent scientists and engineers. The Process Specification Language and the Manufacturing Simulation projects are particularly impressive.

Staff members are generally enthusiastic and expert in their areas of endeavor. They frequently publish the results of their high-quality work; they participate in major conferences, standards organizations, and industry consortia; and they have organized and led a number of strategic workshops during the past year.

The MSID has continued its significant effort to implement a program structure that would enable it to improve performance, focusing this year at the project level. Projects have been technically aligned with the programs and the mission. The division should continue these efforts, increasing focus on the areas of outreach and customer participation. MSID has also started and should continue a programmatic effort to attract and train appropriate personnel in the areas of formal specifications, semantic representation, knowledge-based systems, ontologies, and software conformance.

MSID's increasing emphasis on cross-divisional work is appropriate. Since the division is involved in information- and knowledge-based manufacturing, there should be significant overlap between projects in this division and other MEL divisions.

In order to address project life-cycle issues, MSID management should define criteria for success and criteria leading to the termination of a project. Almost all of the programs reviewed this year by the panel are scheduled to end at the same time; MSID management should consider whether it is feasible and useful to arrange a mix of programs, with some beginning while others are ending and still others are in the middle of the program time line. The division should also investigate the inclusion of electromechanical assemblies in the Product Engineering Program.

Program Relevance and Effectiveness

MSID's main objective is to help manage the ever-increasing complexity of the manufacturing environment, in which new systems continually make old ones obsolete and may perform new functions not previously considered part of the manufacturing enterprise; in which new languages, software, operating systems, hardware platforms, software platforms, and communication protocols are introduced with little coordination or external control; and in which competition is fierce and cost-consciousness is increasingly prevalent.

As a result of these challenges, MSID is heavily engaged in work on interoperability issues, which involves understanding how parts of the manufacturing enterprise work together and how this working together may be automated in response to systems with a complexity that may be beyond human capabilities to understand. The rapidity of change encourages manufacturing engineers to work with MSID, which fills a niche in the manufacturing environment not filled by other university, national laboratory, or vendor programs.

To address its objectives, MSID is faced with the challenge of balancing resources and attention between applied research (demanding rapidly available practical solutions) and basic research (involving issues that require longer time periods to develop theories and solutions).

It appears that MSID is managing this difficult role. The scientists and engineers are frequently both technically competent and practically oriented, expressing a desire that the results of their efforts be incorporated into practical manufacturing activities. They also bring together the academic, industrial, and government communities, fostering communication and cooperation between these often-disparate groups.

MSID disseminates results to the user communities by participation in relevant organizations, consortia, user group meetings, conferences, and seminars. The division's effective job of disseminating results should be augmented by a strategic outreach plan for marketing to customers. This is especially important at a time of shrinking budgets.

Division Resources

As of March 2003, there were 31 full-time permanent employees of MSID, 23 of whom were in technical positions; this reflects no change from last year. There were, in addition, 6 other full-time staff, who include postdoctoral research associates, students, faculty, and other nonpermanent people—2 more than last year. There were 30 guest researchers, many of whom have long-term associations to the MSID programs. The current number of guest researchers is less than last year: short-term appointments have been cut back, while long-term commitments are being maintained. The majority of MSID staff, therefore, is composed of nonpermanent staff. The panel is concerned that there may be little to no ability to replace key personnel. The flat or slightly decreasing budget and the decrease of the permanent staff are the two important related concerns.

MSID has leveraged resources by using guest researchers, creating an interesting mix of permanent and flux employees, but it is concerned with maintaining institutional memory and core competencies. Furthermore, the permanent staff is typically the source of future management, and if this group continues to shrink, it will have long-term implications on MSID.

Postdoctoral positions are an important asset to MSID, but the division has not had much success at attracting postdoctoral candidates. The reasons for this difficulty should be explored and, if feasible, corrected. Significant encouragement has been given to research staff members to further their knowledge through seminars, short courses, invited lectures, and enrollment in higher-degree programs. This encouragement should continue.

While there has been little overt change in the number of projects over the past year (only one project gracefully ended), there was a subtle movement in shifting the effort of several people (e.g., refocusing away from work on behalf of committee memberships toward work in new research directions in interoperability). The nanotechnology effort was refocused successfully. It is anticipated that several projects will end in the current fiscal year, and approaches such as refocusing should continue, where effective and appropriate, so that the newer efforts such as homeland security and health care can be supported in spite of constrained funding and staffing.

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Chemical Science and Technology Laboratory: Division Reviews

BIOTECHNOLOGY DIVISION

Technical Merit

The purpose of the Biotechnology Division is to maintain a research laboratory as the primary resource for the biotechnology measurements, models, data, and reference standards required to produce biochemical products, enhance competitiveness in the world market, and allow the government to apply advances in biotechnology to the benefit of society. The Biotechnology Division has four groups: DNA Technologies, Bioprocess Engineering, Biomolecular Materials, and Structural Biology. The emerging Bioinformatics Group, mentioned in last year's assessment, remains as part of the Structural Biology Group. This year the division is under new leadership; the Bioprocess Engineering Group leader has been replaced and is now division chief.

The DNA Technologies Group is pioneering a number of important methods. These include the development of SRMs for human identification and a critical database on short tandem repeats (STRs). The group also houses the NIST/National Cancer Institute (NCI) Biomarker Validation Laboratory (BVL), part of NCI's Early Detection Research Network (EDRN). Other programs include the genotyping of single nucleotide polymorphisms and the establishment of methods for detecting and quantifying DNA damage and repair in cancer detection and treatment. This research is state of the art and continues to push the technology into new, productive, and high-impact areas.

The Bioprocess Engineering Group focuses on developing measurement methods, databases, and generic technologies related to the biomolecular field in manufacturing. The group is active in biocatalysts, biospectroscopy, biothermodynamics, and DNA separation and measurements. The group's work is of high quality and is clearly described in a well-designed Web site (www.CSTL.nist.gov/

NOTE: Chapter 4, "Chemical Science and Technology Laboratory," which presents the laboratory-level review, includes a chart showing the laboratory's organizational structure (Figure 4.1) and a table indicating its sources of funding (Table 4.1).

biotech/bioprocess/projects.html). The Biomolecular Materials Group focuses on studies of biological molecules and their potential uses in biotechnology. One emphasis is the study of thin films leading to determinations of the surface effects or character of biomolecules at surfaces. A closely related interest concerns the construction of biomolecular polymeric structures that act as scaffolds for tissue engineering. A particularly promising project involves single-molecule measurement using pores of nanometer scale. Each of these studies is making fundamental advances in the understanding and control of biomolecular materials engineering.

The Structural Biology Group participates in the Center for Advanced Research in Biotechnology (CARB), a joint NIST/University of Maryland research center located on the Shady Grove campus of the university about 4 miles from NIST. Scientists at CARB develop and apply measurement methods, databases, and state-of-the-art modeling methods to advance the understanding of protein structure/function relationships. The individual programs are outstanding, and the group contributes a number of important resources such as the Protein Data Bank (PDB) to the world scientific community.

Program Relevance and Effectiveness

The Biotechnology Division faces unique challenges and vast opportunities resulting from the breadth of topics in the biological sciences, the rapidly changing nature of technology supporting new discoveries in life sciences, and the continuing emergence of new biotechnologies. To meet these challenges, it will be necessary to have a critical mass of personnel and equipment to address the appropriate issues in metrology and standards for each opportunity. A division 10 times the size of the current Biotechnology Division could not respond to all of the possibilities. Thus, the division must continually evaluate and reevaluate its portfolio of projects to ensure that they closely reflect and anticipate commercial needs. The recent adjustments in personnel within the division reflect this sense of reprioritization.

In some cases, both critical mass and appropriate range of expertise can be obtained only by cross-divisional or cross-laboratory projects. Also, collaboration with external entities is clearly one method to leverage NIST resources; CARB is a good example. For CSTL, the challenge is to ensure that biology is incorporated appropriately into all divisions while fostering and enhancing within the Biotechnology Division a strong core of integrative biology (across molecular and physiologic scales) that is both current and quantitative in orientation.

Overall, CSTL and the division have responded well to these challenges, although continuous reevaluation of the project portfolio remains a critical part of any strategy to respond to changing customer needs. The division can conduct three basic types of projects: (1) those responsive to current, identifiable needs; (2) those for the development of internal expertise in emerging areas in which evaluation and standardization of methodology are likely to be important; and (3) those for the development of new measurement technologies that, in themselves, will foster new biotechnologies. Examples of the first category are the Protein Data Bank, a real gem for NIST, and the effort to develop methodology for the sampling and detection of genetically modified foods (a critical commercial need). Examples of projects of the second category (for internal expertise) are those on proteomics and RNA-protein interactions. In particular with the Proteomics project, issues of standardization and validation are almost certain to emerge. An example of the third type of project is the cross-divisional effort, Single Molecule Manipulation and Measurement (SM3) initiative, which has a high probability of establishing new measurement methodology. The panel believes that all projects in the division's portfolio should be justified in one of these three categories. Within each category, the division must be willing to prioritize project value and eliminate less valuable although technically sound projects. To minimize the elimination of technically sound projects, the division may need to seek out more extradivisional partnerships to satisfy critical mass on some projects (e.g., partner with CSTL's Analytical Chemistry Division on analysis of genetically modified organism [GMO] foods). Overall, the division has made defensible choices in the project portfolio, adjustment of personnel, and partnering in cross-divisional or cross-laboratory projects and external collaborations.

The division continues to maintain high external visibility and programmatic relevance. It functions with the fairly high level of external funding that it has received to support its programs. Such funding has positive aspects, since it requires the group to maintain a high degree of customer responsiveness.

The division has an ambitious portfolio of research projects that fall into the categories of health and medical products, forensics and homeland security, and food and nutritional products. Several projects serve as useful examples of responses to current, identifiable needs (category 1 projects) and highlight the breadth of program relevance. In the Human Identity/Forensic Science project, the division is developing new methods for DNA profiling, ranging from developing well-characterized DNA standards for restriction fragment-length polymorphisms to performing research for rapid determination of DNA profiles by polymerase chain reaction (PCR) amplification and automated detection of fragments. These new methods have proven important for the identification of victims of the World Trade Center disaster of September 11, 2001, since the high degree of DNA fragmentation due to the severe environmental conditions meant that only about 50 percent of the specimens yielded results under standard DNA testing methods. An important project in the area of DNA diagnostics for the detection of human disease is the NIST component of the NCI Early Detection Research Network. This NIST project serves to refine recently discovered cancer biomarkers and to format new research tests for field trials in EDRN clinical laboratories. The rigorous validation of biomarkers for diagnostics is a critical issue that fits well with the development of measurement methodologies. These projects will offer high-impact improvements to human health.

In 2002 the panel was concerned that the Proteomics Group might be spreading itself too thin and thereby limiting its ability to mount the kind of program needed in proteomics. However, the panel is now comfortable with the strategy of a small proteomics effort to develop the internal competency to assess developments in the field that will determine future NIST directions.

A program that focuses development of new measurement technologies is the program on advanced mass spectrometry measurements of DNA damage. For example, the cellular accumulation of two major oxidative stress-induced DNA lesions in cells of Cocaine Syndrome patients after exposure to ionizing radiation has been identified. As a disease with implications for understanding the human aging process, these studies are undertaken as a collaborative effort with scientists at the National Institute of Aging. The program researchers and management should continue to carefully assess priorities and resource distribution to ensure that key programs are adequately supported. The group should also develop a plan that prioritizes its efforts in a way that is consistent with ongoing commitments and its current expertise base.

The DNA separations and analysis projects are responsive to current, identifiable needs. These projects focus on GMO testing (a critical issue for agriculture and global trade), identification of pathogens (important for medicine and homeland security), and the development of DNA standards for use in industries involved in DNA vaccines and gene therapy. Much of the work in the biocatalysts and biothermodynamics projects has focused on understanding the chorismate biosynthetic pathway (enzymes, thermodynamics, and so on). This pathway is important in agriculture and in the biomanufacturing of aromatic amino acids and related compounds, and it has served as a model system for studying metabolism. The biospectroscopy projects address primarily categories 1 and 2. The development and production of fluorescent reference materials in the biospectroscopy project also address current, identifiable needs.

Much of the other work in the division involves the development of internal expertise in emerging areas in which evaluation and standardization of methodology are likely to be important, such as broader application of fluorescence. Although it is appropriate for NIST to take the lead in GMO testing, this work is supported by only two people, who are also involved in several other projects. To increase the critical mass on this project, the Bioprocess Engineering Group should enhance its level of collaborations with both internal and external groups. The chorismate pathway project has been very successful; however, the panel recommends a reconsideration of this work and its contribution to the mission of the division.

The issue of changing the group name to something other than Bioprocess Engineering came up several times during the panel review. The reason for concern seems to be that "Bioprocess Engineering" does not accurately reflect the scope of the group and may be misleading to internal and external collaborators. One suggestion provided to the panel was "Biophysical Measurements," but this name seems too broad. Another, narrower suggestion was "Bioprocess Measurements," which may be too narrow. The panel recommends that the group continue to think about names that reflect its scope and purpose.

Finally, the panel was encouraged by the efforts within the Bioprocess Engineering Group in the area of homeland security. These efforts include a substantial program funded by the Air Force. The group is also preparing a white paper on opportunities in this area for the Biotechnology Division as a whole.

The Structural Biology Group continues to realize its potential as a high-quality program with international impact. The CARB center addresses projects in X-ray crystallography, biomolecular nuclear magnetic resonance (NMR) spectroscopy, protein folding, computational chemistry and modeling, and mechanistic enzymology. This work can be characterized as being in categories 2 and 3; it is outstanding. A stimulating research environment exists within CARB, and it maintains the mission-oriented flavor critical to NIST programs. The value and uniqueness of CARB appear to be fully appreciated by NIST senior management, which views it as a paradigm for future NIST/academic ventures.

Last year the panel expressed concern that NIST staffing levels at CARB were too low, and several decisions have been made in the past year to increase the NIST presence at CARB. The low staffing-level trend is being reversed by relocating the Protein Data Bank workforce to CARB, where natural scientific synergies exist. The NIST campus will continue to provide hardware support. The PDB, a category 1 program, is the premier world resource for data on protein structure and function and as such showcases NIST's role in biotechnology. The PDB Web site records approximately 6 million hits a month, providing an impressive metric of its value to the scientific community. As part of its move to increase the NIST presence at CARB, CSTL merged its Bioinformatics and Structural Biology Groups at CARB.

Overall, the programs at CARB continue to be highly relevant, and the moves to bolster the NIST presence are important. However, the success of the CARB experiment should not obscure the need for a continued strategic plan. CSTL should develop a long-term plan that clearly describes what its future vision of NIST's role at CARB is and how it will respond to new growth initiatives for CARB from the University of Maryland. A clear plan of commitments will be an important component in attracting a first-rate director for CARB.

Division Resources

With respect to division resources, the issues of critical mass and portfolio review merit attention, given the breadth and depth of current interest in biotechnology. The division cannot do everything. Considering the wealth of opportunities in this field, the panel believes that the division's staff should be growing and is concerned that in fact it seems to have decreased slightly. On the other hand, the panel is encouraged that some restructuring between groups was done to staff new projects more efficiently. The facilities and equipment in the division are excellent and adequate to fulfill its mission.

The DNA Technologies Group lost two full-time employees, who were transferred to the Bioprocess Engineering Group in a move to align expertise (the restructuring mentioned above). The DNA Technologies Group boasts a number of state-of-the-art resources. The high-speed matrix-assisted laser desorption ionization (MALDI) time-of-flight mass spectrometers with automated sample preparation, capillary electrophoresis (CE), and gas chromatography/mass spectrometry (GC/MS) facilities are excellent.

The Structural Biology Group has maintained constant staffing over the past year. The group is well outfitted for cutting-edge research, given that the X-ray diffraction and ultrahigh-field NMR facilities are outstanding. The PDB resources are impressive.

The Biomolecular Materials Group lost one full-time employee in the past year. The group's relatively small size restricts its ability to take on new projects and continues a long-term trend in loss of faculty. The facilities and equipment available for the work of this group are excellent.

PROCESS MEASUREMENTS DIVISION

Technical Merit

The Process Measurements Division of CSTL provides a central, national source for reference materials, calibration of measurement equipment, and data on materials properties. A core responsibility of the division is the improvement and dissemination of national measurement standards for temperature, fluid flow, air speed, pressure and vacuum, humidity, liquid density, and volumetric measurements.

To facilitate communicating the panel's findings concerning the Process Measurements Division, a summary is first provided, followed by details of the visits to each of the division's groups.

The technical quality and merit of the Process Measurements Division can be illustrated by the following achievements during FY 2003:

- Achievement of the ability to concentrate an analyte ~10,000× in a microfluid environment. The panel is impressed with the clever use of thermal and electric-field gradients used to achieve this competence;
- Involvement of the division with two NIST Competence projects, which in the panel's view speaks to the quest for excellence and for advancing the state of the art in measurement science;
- Development of a new piston calibrator for jet fuel flow sensors and pioneering of a unique design for a diverter valve needed to reduce the uncertainty of large water flow calibrations;
- Capturing the distinction of being first in the world to advocate the use of the backscattering configuration for Raman spectroscopy to eliminate polarization effects as sources of intensity differences for samples measured by different laboratories, and development of an advanced mathematical model to simulate such scattering by ternary and quaternary III-V compounds;

- Completion of a study of the intrinsic stability of sensors without their electronics, which indicated that the electronics may be limiting the uncertainty and therefore will require improvements to match the stability of MEMS pressure sensors;
- Development of plans to explore standardization needs in the area of dynamic pressure measurement; and
- Adoption of ISO/IEC 17025 standards for all calibration projects.

The panel continues to be impressed by the concentration of measurement knowledge and expertise in this division and by the quality of its work. Delving more deeply, the panel was especially impressed with the ongoing projects discussed in the following subsections.

Molecular Electronics

Molecular Electronics—a competence project funded at approximately $1.3 million per year for 5 years (it is in its third year)—appears to be a model for its breadth, integration of talent at NIST (six groups in three divisions and two laboratories), and collaboration with Hewlett Packard and IBM. This project's alternative approach to electronics technology is based on single-electron devices having molecular-sized components, and it uses nonlinear processes that are analogous to silicon-based diodes and transistors. Because the processes originate from synthesized molecules, the dimensionality is much smaller and is more dense than that of traditional devices. The CSTL effort is focused on testing a variety of methods that will provide early input into the feasibility of this approach. One such method is two-photon photoemission, which accesses unoccupied electronic levels and tracks electron relaxation effects. In this impressive project, short pulses (~10 femtoseconds) of variable wavelength from titanium-sapphire lasers are used to analyze molecular structure using the two-photon photoemission technique.

Fluid Science

The division's determination and dissemination of fluid properties respond directly to industry needs for thermal-based mass flow measurement systems, which are limited in performance by the accuracy to which fluid properties are known. Technologies and competencies developed in the fluid science project have been applied by the division's thermometry researchers. Acoustic technology developed in the Fluid Science Group has been applied by the Thermometry Group to primary acoustic thermometry. Improvements to the ITS-90 temperature scale have resulted. This method has been applied up to 575 K, and the goal of 800 K appears obtainable.

This fluid science project is also striving for development of a primary pressure standard based on measurements of the dielectric properties of helium. The goal is to achieve a 10 to 20 ppb uncertainty with the cross-capacitor He-dielectric measurement approach. So far, 100 ppb has been demonstrated. A novel, cross-capacitor made from a single edge-grown sapphire crystal has been developed and shows promise; however, a state-of-the-art capacitance bridge is required to meet the ultimate goal. Vendors are being sought to provide the needed tool. The panel raises a question that must be considered: If a key measurement tool needed for the primary standard is not currently available, does this introduce an extra limitation into the utility of a primary standard? The panel also questions how this approach compares to the resonant silicon pressure sensing approach being pursued by others.

The project continues its ongoing effort to map the thermophysical properties of gases used in semiconductor processing, which is challenging because some of these gases are highly reactive or corrosive. This acoustic resonator R&D area seems well connected with the semiconductor industry and academia and might benefit from closer interactions with the Fluid Flow Group.

Work accomplished by the fluid property measurements project includes the use of an oscillating gas column around a heated honeycomb in combination with an acoustic resonator to measure fluid properties with greater accuracy (η and k to 0.3 percent, ρ and c_p to 0.1 percent, and c to 0.01 percent).

The Raman Spectra Calibration Library has made significant advances in the calibration of Raman spectra by creating Raman intensity standards, promoting the use of backscattering and advanced modeling of the scattering from spatially inhomogeneous samples.

Thermal and Reactive Processes

Optical absorption measurements of synthetic soot produced from the controlled combustion of heptanes are being studied, with the goal of developing SRMs of known composition and with known characteristics. These SRMs will allow users (especially transportation, energy, and environmental industries) to calibrate their instruments, determine uncertainties in their measurements, and develop appropriate models. The Process Measurements Division has a unique technical competency in this area. It would be interesting to see a correlation between the absorption characteristics of soot in the air caused by air pollution and the synthetic soot standards developed as reference materials.

The group developed an SRM for Raman spectroscopy. Raman spectroscopy is becoming widely used in a number of industries, so the need has increased for a simple, reliable calibration technique for this measurement method. The development of a standardized glass (SRM 2241) is a practical approach for providing an easily transferred, stable, intensity calibration source that can be activated by laser light at 785 nm, a common laser wavelength. SRMs used for Raman spectroscopy at other wavelengths will be developed and made available in the future. The panel is pleased with this activity.

Fluid Flow

The Process Measurements Division has continued to improve fluid flow rate measurement capabilities and to reduce uncertainties. The completion of the small PVTt (pressure, volume, temperature, time) system gas flow standard represents a significant milestone, replacing traditional proven piston and cylinder and bell technologies with a fully automated calibrator that had been documented to reduce uncertainty by a factor of 10. This represents a level of accuracy that is best in the world for gas flow rate. A larger PVTt system is under development and approaching completion.

The division has also developed an improved liquid flow rate calibration technique that is expected to have a significant impact throughout the liquid flow rate calibration community. The division has pioneered a uniquely designed prototype diverter valve that provides for self-cancellation of an error source that has plagued gravimetric flow rate calibrator systems for decades. The panel views this accomplishment as a creative solution to reducing the uncertainty of this calibration.

The Process Measurements Division continues to lead the international community through CIPM and Sistema Interamericano Metrología (SIM) working groups. The division is conducting projects for DOD aimed at improving flow rate measurement accuracies for both liquid and gas flow by an order of magnitude. A newly constructed liquid fuel piston calibrator with a flow range of 0.01 to 3 gal/min and accuracy of 0.025 percent is now being tested for a DOD customer.

The division is pursuing development of a low-gas-flow measurement assurance program utilizing a new breed of highly stable commercial flow sensor nozzles and laminar flow elements (annular, $Re \leq 500$, $L/D \geq \sim 2000$). Round-robin testing and participation with outside testing organizations are exemplary. The division also continued the effort to complete the Exhaust Gas Flow Laboratory, which cost between $3 million and $4 million to build. Once completed, this facility will allow the development of important collaborations with the automotive industry.

Process Sensing

With respect to work on microheater sensors, conductometric SnO_2 or TiO_2 film sensors of ~500 Å in thickness and ~100 × 100 μm in size have been able to sense 20 to 200 ppb of sarin and can also detect mustard gas and GA-tabun with a response time of ~50 s. A new, monolithic pre-concentrator may increase sensitivity by 10 times. In addition, carbon nanotube growth on MEMS micro-hotplates has been demonstrated, clearing the way for the evaluation of their performance as gas sensors. Sensitivity, selectivity, speed, and stability issues must still be addressed to improve performance. As with other micro-hotplate microsensors based on doped SnO_2, TiO_2, or differential calorimetry—which promise the possibility of attractive performance parameters such as low power, low cost, and compactness—achieving stable operation over thousands of hours still represents a major challenge and should be considered carefully. This project is relevant to homeland security and chemical warfare agent defense technologies.

Plasma Process Metrology

In 2002 the Plasma Process Metrology project developed a method for two-dimensional mapping of the gas temperature of plasmas using the planar, laser-induced fluorescence method. Results have been shown for a CF_4 plasma operating at several different pressures. This is a nice application for a high-level, advanced metrology method. This measurement method could potentially be used to explore the thermal effects of particles in plasmas which, along with heat transfer studies, will likely be of interest to the semiconductor industry.

In response to last year’s concerns of the panel, the Plasma Process Metrology team has developed a new, inductively coupled, 300-mm plasma process reactor. This system closely resembles the process tools used by chip manufacturers and is a significant advance beyond the tool previously used, which is referred to as the GEC tool.

Microfluidics

The Microfluidics project developed an ingenious approach to both concentrate (≥10,000:1) and separate analyte in liquid/ionic microfluidic streams. This procedure is based on achieving a unique balance of forces on ionic analytes (fluorescent dyes, amino acids, proteins, DNA, and colloidal particles) in overlapping and opposed electric field and temperature gradients (temperature gradient focusing). Concentration of analytes at ratios greater than 10,000 to 1 were demonstrated and considered by the panel to be a significant achievement.

Pressure and Vacuum

The panel discussed with the group leader the merits of developing alternate approaches for supporting calibration service customers. One approach discussed would be to replace such traditional calibration services with “NIST traceable programs.” Such a program might apply processes similar to those used for NIST-traceable reference materials, laboratory intercomparisons, and measurement assurance programs. Among its benefits would be the sort of traceability and proficiency test data required by the customer to meet the requirements of ISO/IEC 17025 standards. The program would benefit the customer by transferring the world-class accuracies of NIST to commercial and military primary calibration laboratories and by providing continuous assurance of accuracy. NIST would benefit by having flexibility in the scheduling of workloads for better utilization of laboratory resources and a more stable income stream.

The panel was told that the cultural change associated with the application of ISO/IEC 17025 standards throughout the Process Measurements Division has been beneficial, and that improvements in the quality of calibration services are expected. An objective evaluation of the impact, if any, of the new quality program on the technical merit of divisional programs would be appropriate after full implementation at the end of 2004. The adoption of ISO/IEC 17025 standards is also applauded by the panel.

Thermometry

The panel noted that the Thermometry Group continues to exert technical influence on the international temperature measurement community, as demonstrated by its developing the program for and peer reviewing articles for the 8th International Temperature Symposium that took place in 2002 in Chicago. The Thermometry Group presented eight papers. The group also completed work on Key Comparison 3 (K3) of the international Consultative Committee on Temperature. NIST was the pilot laboratory for the most comprehensive intercomparisons ever conducted. A temperature range covering –189 ºC to +660 ºC was done.

This past year, the Johnson Noise Thermometer prototype was completed, and a noise-to-power accuracy ratio of better than 0.1 percent was documented over the range considered. The ability to recalibrate such sensors in situ—for example, for space station applications—is viewed by the panel as very significant.

Completion of construction of the acoustic thermometer was followed by validation testing, including the measurement of the temperature of the gallium melting point, which showed excellent agreement with earlier work. Excellent results at indium and tin freezing points give confidence that the division will finally be able to resolve problems in the temperature scale.

Program Relevance and Effectiveness

The Process Measurements Division continues to be responsive and forward thinking in supporting certain industries (e.g., semiconductor and automotive). It was not clear to the panel whether other important segments of U.S. industry (e.g., process, gas, biomedical) were getting the same attention or would perceive the division's programs as relevant to their needs. Overall, this panel was again impressed by the effectiveness and progress toward automation in many of the division's projects.

A fair amount of effort at CSTL seems to be focused on the semiconductor industry. How does this compare to the effort it invests in the other 5 out of the 12 CSTL program areas that the division is supporting? The division has continued efforts to develop and maintain close contact with manufacturers and other customers, including integrated circuit manufacturers, in response to comments made in the FY 2002 assessment.

The division's determined effort to bring all calibration programs into compliance with the ISO/IEC 17025 standards is expected to highlight the relevance of NIST programs, especially in the eyes of its calibration service customers. It would be especially beneficial for NIST to publish its ISO-compliant quality manual and other relevant quality documents on the Web. Commercial and government calibration and testing laboratories could use such documents for a variety of purposes, not the least of which would be as guides and templates for their own documents.

The division provides considerable consultative and advisory services for its calibration customers and researchers. The availability of NIST experts for telephone consultations is a valuable service to U.S. industry and the U.S. government. Providing such assistance is said to consume as much as 25 percent of division researchers' time. NIST seminars and workshops provide another valuable dissemination vehicle for technologists and researchers to interact with NIST experts in their field.

The results of NIST programs and technical information were made available to the public during the past year through a variety of means, including free, Web-based processes, computer media, publications, talks, participation in committees, and workshops. The division's output included 93 publications, 90 presentations, 1 CRADA, 9 patents or patent applications, 1 SRM, 187 calibrations or tests, participation in 96 committees, 1 editorship, and 5 workshops/meetings.

Division Resources

Division facilities continue to show improvement. Construction of the new metrology building is progressing, and the panel looks forward to the day when many divisional areas are able to take advantage of this environment that will be among the best in the world.

Calibration charges to customers currently cover only about 70 percent of CSTL's costs. The panel encourages CSTL to recover its full costs through a combination of cost reduction and price increases. This may result in performing fewer calibrations and transferring more calibration work to secondary standard laboratories, such as CCESI, Flow Dynamics, and Aldan, but would leave more time for research on measurement and calibration automation. The resources of the division are adequate, especially in view of the impending readiness of the new metrology building.

Responsiveness to Panel Recommendations

The division's response to the panel's suggestions in the FY 2002 report to boost Web-based data dissemination was that "data for gases used in semiconductor manufacturing are freely disseminated." This response is not viewed as being especially proactive. There was no mention of adding one property column (viscosity), nor of attempts to relate the division's Web site to other CSTL Web activities.

The panel did not see that resources and structure for increasing the rate of Web-based data dissemination were implemented as recommended.

Additional Comments

The Process Measurements Division has developed and demonstrated the capabilities of microhotplate and microcalorimetry sensors in terms of their high sensitivity, and it could earn high regard in the sensors community if it were able to clarify the fundamental expectations and limitations of the stability of nanoscale and thin-film sensor technology. The panel also suggests that rather than abandoning the established custom of charging for the use of NIST's property data, some minimum access in terms of downloaded megabytes or computer milliseconds over a subscription period could be allotted to each new e-mail address in order to familiarize potential customers and researchers with the hidden wealth of information.

SURFACE AND MICROANALYSIS SCIENCE DIVISION

Technical Merit

The Surface and Microanalysis Science Division performs research to accomplish the following:

- Determine the chemistry and physics of surfaces, interfaces, particles, and bulk materials and determine their interactions with a broad spectrum of analytical probes, including electrons, photons, ions, atoms, and molecules;
- Determine the chemical and isotopic compositions, morphology, crystallography, and electronic structure at scales ranging from millimeters to nanometers;
- Determine the energetics, kinetics, mechanisms, and effects of processes occurring on solid surfaces and interfaces as well as within materials and devices;
- Study the total chemical measurement process as well as source apportionment in atmospheric chemistry using advanced isotope metrology and chemometrics; and
- Develop and certify key Standard Reference Materials and Standard Reference Data.

The overall quality and dedication of the division's staff are extremely high. Since last year's review, the Surface and Microanalysis Science Division has further modified its organizational structure in order to focus its projects on its primary mission. It has reduced the number of groups from four to three, having redistributed the staff assigned to the Atmospheric Chemistry Group to other groups. This change is an excellent example of the division's responsiveness to recommendations of the review panel in the FY 2002 report. The reorganization appears to be an effective step toward concentrating the staff talents on core competencies. The transition is proceeding as important legacy projects are brought to a proper conclusion, and assimilation into the new group structure should be completed this year. The three remaining groups are the Microanalysis Research Group, the Surface and Interface Research Group, and the Analytical Microscopy Group.

The division's technical programs continue to be world-class, with many clearly being at the leading edge of research. During the past year, the division organized six major workshops on a national level and organized a number of sessions at other types of conferences as well. The division has participated in important site visits to approximately a dozen major companies and is involved with a number of important CRADAs. Furthermore, it has active collaborations with several external companies, both domestic and international. Multiple collaborations with other NIST laboratories and external supporting organizations attest to the high value of its scientific work. The division has also presented numerous important technical papers and talks at both domestic and international technical conferences. This output attests to the intent of the division to share appropriate results with the professional community in order to further the general aims of the scientific community. All of this speaks very well for the division and its current activities.

The research work performed by the Microanalysis Research Group has long been noted as being world-class and leading edge. Many of the standard techniques used worldwide in microanalysis are almost fully based on this valuable NIST program. Recently, this group has shown its determination to retain its research leadership by continually developing new approaches to what has been standard methodology. An example is the use of the NIST microcalorimeter in Boulder to obtain high-resolution X-ray spectroscopic data and apply them to the problems of electron probe microanalysis. This major development in instrumentation is currently being commercialized in the United States and Europe by two instrument manufacturers. Although it is unfortunate that intellectual property issues in NIST kept this technology from being widely distributed for some time, that problem has apparently been solved, and commercial instruments are in the early stages of beta site installations. The impact of this instrument will be significant owing to its rapid throughput and its high-energy resolution. The group continues to maintain its world leadership by having early access to the tool, which is now in Gaithersburg, and by demonstrating its practical applicability. It is expected, on the basis of this work, that this instrument will eventually change the complexion of manufactured electron probe microanalysis systems.

A further example of the Microanalysis Research Group's intent to retain leading-edge capability is its current exploration of the silicon drift detector, also for X-ray spectroscopy. Although the resolution of this tool is comparable to that of the older semiconductor detectors, the speed of data access will most likely lead to its widespread industrial application, since the speed of data acquisition is essential for the control of complex manufacturing processes. Data collection speeds are expected to improve by as much as two orders of magnitude with the use of this technique in some circumstances.

The development of an XML data format for spectroscopic hyperdata in the Transmission Electron Microscope Laboratory is extremely important, and the division is to be commended for supporting this work. This general data format allows for very impressive methods of spectral data storage and analysis and is destined to become a standard, nationally accepted format. This is, of course, completely consistent with the mission statement of CSTL. This hyperspectral data storage tool applies to more than the X-ray spectra demonstrated to the panel, and widespread utilization is to be expected.

Program Relevance and Effectiveness

The opening remarks from late year's summary of the Surface and Microanalysis Science Division remain valid and are simply repeated here for reference:

> The Surface and Microanalysis Science Division uses a variety of methods to ensure the relevance and effectiveness of its programs. It is mapping key activities to the NIST Strategic Focus Areas. For example, nanotechnology is supported by the division's project on cluster-ion SIMS for high-resolution depth profiling, the Competence program on molecular electronics, and overall general chemical imaging. Support of homeland defense has been an integral part of the division for many years, with projects in forensic particle analysis, quality assurance and control methods for the U.S. Atomic Energy Detection System (USAEDS), gas mask standards, and analysis of explosives particles. The division has new activities in support of health care, including monitoring boron neutron capture chemotherapy using SIMS analysis of tissue samples, drug delivery using nonlinear optical spectroscopy, nanoscale analysis of compounds of pharmaceutical interest using near-field scanning optical microscopy.[1]

It remains unclear, however, how carefully these programs are coordinated with other projects in CSTL, the larger NIST, other national laboratories, and external university and industrial research.

The large number of industrial visits this year is laudable but, as mentioned in last year's report, more extensive utilization of the NIST Industrial Fellows Program is encouraged. Such longer-term interactions with industrial and university laboratories would assure CSTL that the work that it is doing in the area of standards development is, in fact, the work that is required by these external researchers to facilitate their R&D efforts. Although these in-depth interactions are possibly limited by funding and heavy staff responsibilities, it is critically important that they be fostered, even if internal programs might be temporarily delayed in the process.

[1]National Research Council, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2002*, National Academies Press, Washington, D.C., 2002, p. 106.

The decision-making process used in defining individual projects in the division is also not particularly clear. Although most of the work that the panel has seen is of outstanding quality and relevance, some projects seem to have been based on individual researchers' interests rather than a clear connection to the mission of the division. It is very important that these connections be made and justified.

It is clear to the panel that the visibility of the Surface and Microanalysis Science Division in the technical community is quite high, from the number of presentations made at professional society meetings or meetings organized by the division's staff. The division organized five workshops of critical importance and also organized sessions at other meetings as well. This activity is commendable and indicates that the division takes a leadership role in many aspects of surface and microanalysis science.

The panel is quite pleased to note that some highly relevant standards have been developed and applauds the division's efforts in this regard. The work on the provision of intermediate "golden standards" is also a critical response to industrial needs that cannot be satisfied by a true SRM, which would take much longer to provide to the nation's researchers. This work has clearly been very effective in supporting industrial needs.

It did not appear clear to this panel that division projects are carefully controlled for duration and results. Some projects that have been continuing for some time do not seem to be much closer to their targets. Decisions should be made on the basis of realistic project goals as well as the importance and viability of the individual efforts. Consideration of standard project management and tracking methodologies with milestones should be made by the division and utilized where appropriate.

The continuing program to characterize single crystals of silicon-germanium will have a profound impact on the semiconductor industry, but it must be emphasized that the window for completion of this work is a small one. Clearly recognizing this problem, researchers working on this problem have defined a class of "Interactive Materials" which, although not SRMs, will allow industry to have a reasonably well characterized material upon which to base analyses, with the expectation that other laboratories utilizing these materials will come reasonably close to the same results under similar operating conditions. The panel commends the development of such Interactive Materials and suggests that the approach be spread more widely throughout NIST.

The work to reduce the relative error in electron-probe microanalysis is obviously very important, and it appears that progress is being made. However, the panel is concerned that although this program has been in existence for a while, no executive-level summary has been offered from which the progress can be gauged. Expected project milestones for such long projects should be made available to review panels, and some method of tracking progress must be available. This comment also applies to other, relatively long-term projects in this and other divisions.

The Surface and Interface Research Group continues to do very important and leading-edge work. This group is investigating infrared near-field scanning optical microscopy in a way that is intended to advance the capability for obtaining high-resolution surface information. The technique will produce a 50-fold increase in lateral resolution while maintaining the spectroscopic capability of Fourier transform infrared spectroscopy (FTIR). The group is also developing confocal Raman microscopy as a tool for surface and interface characterization. Increasing the chemical information content of surface and interface analysis techniques is a very important goal. The combinational instrument approach, the inclusion of a range of techniques in a single instrument, is clearly pushing instrumental capabilities and developing techniques that will have great industrial applicability. The panel commends these efforts as being clearly in line with the division's mission. The exploration of tools to characterize molecular electronics is therefore being carefully balanced in such a way that the measurement techniques will have widespread applicability in other technical areas as well. The group is exploring the basis of enhancing imaging phenomena so that measurement protocols will be scientifically based. The group thereby established that contrast is not an absorbance phenomenon. The materials distributed to the panel by this group also demonstrated that very specific industrial companies were to be the beneficiaries of this work, again in keeping with NIST's overarching mission statement.

The Analytical Microscopy Group works on a number of highly varied projects. The critical nature of this work does not require elaboration, and the division is quite up to the task of providing critical information in this area of national need. An important project was the development of methods for the trace detection of explosives, a program clearly related to the needs of homeland security. This work involves the characterization of particles that come off clothing via air bursts, swipes of luggage, and so on. The detection and identification of such particles should probably involve wider cooperation within and outside of CSTL, because many pockets of expertise throughout NIST are relevant to this work. The determination of the scientific underpinnings for such work is critical and appears to be receiving appropriate attention in this group. An important focus of the work with the chemical characterization of particulate matter relates to homeland security, with work concentrating on explosives with the Transportation Security Administration, dirty bomb characterization, and gas mask calibration.

The development of secondary ion mass spectroscopy (SIMS) SRMs for implant standards seems to be leading to successful SRM introductions, but the panel believes that these materials should have been developed and distributed much sooner. The "Interactive Materials" mentioned above clearly have an important place in this program because of the complexity of SRM development and its obvious conflict with industrial timescales. Nevertheless, the development of these standards is commended and is recognized as an extremely valuable contribution. The understanding of degradation mechanisms for such standards is clearly being addressed. It is useful to emphasize how important and useful this work has been to the semiconductor industry.

The work on particle and isotope methodology seems to be a collection of legacy projects as the staff explores next steps, with the division reorienting the original Atmospheric Chemistry Group along its primary competencies. Several of these projects—for example, the enhanced sensitivity of the cobalt-60 autoradiography over gamma spectroscopy and the collaboration with the University of Maryland—have provided particularly practical information. One example of a legacy project involves the characterization of asbestos particles, which does not appear to be particularly innovative.

The work reported on Auger and Electron Spectroscopy for Chemical Analysis databases is extremely important internationally and is recognized for its quality and usability. The panel was told that the database receives "thousands of hits" by professionals in any one month and is thus a very important tool for the surface science community. The panel believes that funding for this work is not adequate.

A number of the technical presentations to the review panel did not consistently convey the objective, the significance of the accomplishment, or how the results would be used by U.S. industry. The panel recommends that more careful attention be paid to the quality and uniformity of presentations.

The foregoing critique should be recognized as being in the spirit of fine-tuning; the panel strongly believes that the work of the division is highly relevant to the goals of CSTL and of the nation. The effectiveness of these programs is clearly indicated by the high regard that most external organizations, educational and industrial, have for the work of the division. A picture of high quality and effectiveness is characteristic of the division, and this should remain in focus as these remarks are interpreted.

Division Resources

The Surface and Microanalysis Science Division has 39 full-time permanent employees as of January 2003, substantially the same as in the previous year. The panel is concerned, however, that the ratio of technical support to professional employees is far from optimal. NIST professionals still find themselves doing a great deal of work that does not really fully utilize their capabilities. Instrumentation upkeep appears to be adequately covered by service contracts. Most industrial organizations have found that the expense of technical support personnel usually translates into more effective and productive utilization of its professional staff. Thus, the panel suggests that as opportunities arise to replace professional staff, a plan should be put in place that would, over some reasonable period of time, evolve the staffing levels into a more appropriate ratio of professional to support staff. The panel expects that this issue will be addressed.

The previous panel suggested changes in the Atmospheric Chemistry Group. The division responded by eliminating the group and redistributing the staff to other groups. The logic for this move was made clear, but the current panel is not sure that the older projects have not continued, albeit in a different area of supervision. Some of these projects are clearly important, but project deadlines for the completion of this work should be made clear. A careful plan to absorb all of these staff members into their new group environments should also be created.

The division's numerous postdoctoral employees add greatly to the vitality of the organization and might benefit from opportunities for closer mentoring. Their lack of understanding of the reward system utilized by NIST should be corrected. There is a perceived lack of direct interaction and communication between staff management and staff members. Drop-in laboratory visits are encouraged.

The division seems to be well equipped with modern instrumentation, but some of it, although fully functional, is quite old and in need of updating. For example, the electron microprobe has been updated with new spectrometer fixtures and software and electronics, but the purchase of more modern instrumentation would probably have been more cost-effective. Last year the panel took note of the fact that the Microanalysis Research Group did not have access to an in-house focused ion beam (FIB) system. The FIB has become the standard method for preparing samples for transmission microscopy as well as for scanning electron microscope observation and analysis. Clearly there is much to understand in the artifacts presented by such samples prepared by FIB tools, and NIST is clearly the appropriate place for this work to be done. FIB was, in fact, to be made available to CSTL, but funding reversals caused this item to be temporarily dropped. This panel very strongly recommends that this instrument be procured as quickly as possible, so that the Microanalysis Research Group can maintain its world-class leadership in this analytical regime. The panel views this issue as crucial and needing immediate attention.

The recent purchase of a SIMS instrument seems to be meeting specifications and proving to be of great value. Unfortunately, the new Auger system has, after quite a few years, failed to meet its specifications. Future equipment purchases should better protect NIST from failure of suppliers to appropriately meet required instrument specifications, and financial sanctions should be included in purchase agreements.

From the perspective of meeting its primary goals, the instrumentation suite is nevertheless world-class, and in the area of microanalysis the division is clearly a world leader.

PHYSICAL AND CHEMICAL PROPERTIES DIVISION

Technical Merit

The Physical and Chemical Properties Division serves as the nation's reference laboratory for measurements, standards, data, and models in the areas of thermophysics, thermochemistry, and chemical kinetics. The panel commends the division for its excellent balance between experimental and theoretical expertise in all areas of the program, and particularly notes the continued emphasis on maintaining its unique experimental capabilities. This emphasis is important, as experimental work continues to be deemphasized throughout the thermodynamics community. Loss of expertise in combustion calorimetry with the recent retirement of the project's principal investigator was noted by the panel.

The division conducts work of unsurpassed quality in making fundamental measurements of thermophysical and thermochemical properties. Division research is organized around eight focus areas that cut across group project boundaries: basic reference data; computational chemistry; fundamental studies of fluids; tools for chemical analysis; cryogenic technologies; measurements for the environment; data for process and product design; and properties of energy-related fluids. Selected highlights of these programs are presented below as a means of illustrating the high technical merit of the work that is performed. The division consists of six groups, three at Gaithersburg (Computational Chemistry, Experimental Kinetics and Thermodynamics, and Chemical Reference Data and Modeling) and three at Boulder (Experimental Properties of Fluids, Theory and Modeling of Fluids, and Cryogenic Technologies). Additionally, three independent projects are also located at Boulder (the Thermodynamics Research Center, the Membrane Science and Technology project, and the Properties for Process Separations project).

Computational Chemistry

An example of outstanding theoretical work within the Computational Chemistry Group is the recent study of transferability of hybrid functionals highlighted in *Science* magazine in October 2002. Significant increases have occurred in the external use of the Computational Chemistry Comparison and Benchmark Database developed by the group since the database became available to the public 3 years ago. Additionally, the group has been active in the organization of conferences related to computational chemistry; examples include the First Industrial Fluid Simulation Challenge, in collaboration with the Boulder-based Theory and Modeling of Fluids Group, and the first of a new conference series on computational biophysics, which was organized and co-chaired by the group leader.

Experimental Kinetics and Thermodynamics

The Experimental Kinetics and Thermodynamics Group provides reliable kinetic and thermodynamic data and standards pertaining to industrial processes, environmental chemistry, energy efficiency, and fire suppression. Its products include evaluated kinetic and thermodynamic data, evaluated chemical models, computational tools, data compilations, and thermodynamic standards.

The group has continued to increase Web-based access to its data. Particular achievements this past year were completion of a project to put the NDRL (Notre Dame Radiation Laboratory)/NIST Solution Kinetics Database on the Web and initiation of a project to make thermodynamic data evaluations Web-accessible. The group has also made use of the Web to make spectroscopic data obtained from a variety of sources widely available. These data include vacuum ultraviolet spectra critical to the development of new lithographic tools for semiconductor production and infrared spectra on a wide range of halocarbons to aid in the calculation of global warming potentials.

The recent development of an indium thermal analysis standard in collaboration with the German standards organization Physikalisch-Technische Bundesanstalt was a successful operation in which the capabilities of the two organizations were combined to produce a new differential scanning calorimeter standard for industry. These collaborative efforts are critical to leveraging the world-class thermodynamic capabilities of NIST.

The panel is pleased to learn that the problems associated with the kinetics database are being addressed by assigning the abstracting tasks to members of the group. This solution has the additional advantage of providing more expert commentary on the data. The panel applauds the effort to make information from both kinetics databases accessible from the WebBook (http://webbook.nist.gov) and recommends that these efforts to integrate the data activities across the division be continued.

Chemical Reference Data and Modeling

The Chemical Reference Data and Modeling Group recently released a major update of the NIST Mass Spectral Database. The new release features major improvements in both coverage and quality. Spectra for more than 54,000 compounds were added, bringing the total to 147,198 compounds. Spectra for 1,735 commercial compounds of special interest were measured by GC/MS at NIST. More than 16,000 spectra formerly in the main library were replaced by higher-quality spectra. All Chemical Abstracts Service registry numbers were verified, and more than 40,000 new registry numbers were added. Annual sales continue at 2,500 units, representing one-half of the GC/MS instruments sold worldwide.

The NIST Chemistry WebBook has been continuously available for the past 5 years and is now being used at a rate of 500,000 users per year (as defined by distinct Internet Protocol addresses), with 50 percent being return users. Review work on WebBook sources for ion chemistry is ongoing with partners at the University of Tennessee and in New Zealand. Future addition of information on the safety of reactive chemicals is under discussion with the Synthetic Organic Chemical Manufacturers Association, the American Association for Clinical Chemistry, and the Chemical Safety Board.

The NIST automated mass spectral deconvolution and identification software (ADMIS), originally developed to facilitate the detection of chemical weapons in support of the international Chemical Weapons Treaty, is finding more applications in other large-scale analysis projects. Examples include the detection of pollution in waterways and the determination of effects on genetic changes in food, as well as anticipated additional uses in homeland security.

Experimental Properties of Fluids

The Experimental Properties of Fluids Group collaborates closely with the Theory and Modeling of Fluids Group to enhance the value of basic data used by industries involved in refrigeration, air conditioning, solvents, and natural gas technology. The group's significant accomplishments during FY 2003 include the completion and commissioning of the world's most accurate instrument for measuring P-ρ-T properties, the double-sinker densimeter; measurements of additional thermophysical properties of several of the new refrigerants; and progress on the development of a physical properties database for ionic liquids. The panel was particularly impressed by the group's ongoing contribution to the development and dissemination of thermophysical data for refrigerants being used to displace ozone-depleting chemicals.

Theory and Modeling of Fluids

The Theory and Modeling of Fluids Group performs theoretical and simulation studies of the thermophysical properties of fluids and their mixtures. The group has made important advances in obtaining properties of aqueous mixtures by ab initio calculations combined with molecular simulations. The second virial coefficients of a number of gas/water systems were obtained over large temperature ranges with uncertainties smaller than those in the experimental data. This work is an example of the synergies possible between the unique experimental measurement capabilities and theoretical work within the division. In the past year, in collaboration with other researchers in the division, this group also obtained diffusion coefficients of salts in supercritical steam and released Version 7 of the REFPROP database.

Cryogenic Technologies

A recent advance is the scale-up of pulse-tube refrigerators (developed in the Cryogenic Technologies Group) to large capacity—that is, 500 W at 30 K—from the smaller-scale 5- to 20-W applications that continue to be used across a wide spectrum of applications from radio astronomy to superconducting electronics and superconducting motors. Design of this scale-up required that extensive instrumentation for a test-regenerator and pulse-tube apparatus be constructed in order to conduct laboratory studies of the refrigeration losses that begin to dominate as capacity is scaled up. Loss sources noted and quantified include flow misdistribution, increased axial conduction, and gravity-induced convection, among others. This past year also saw the completion of the 11 L/h two-stage pulse-tube Neon liquefier and transfer of the system to Praxair; technology transfer with this industrial partner is ongoing. The Neon liquefier is a good example of the types of associations with the more than 29 cryogenic companies that have been industrial partners of the group through consultations and CRADAs.

Thermodynamics Research Center

Significant and rapid progress has been made since the transfer of the Thermodynamics Research Center (TRC) to NIST Boulder in mid-2000. The TRC Data Entry Facility is up and running in high-quality space. An important development in the past year has been the adoption of the thermal data format standards, developed by TRC and collaborators, by a number of major journals in which primary thermodynamic data for fluids are published. The thermal data format is based on XML and greatly facilitates error-free exchange and storage of thermophysical data. These data will be used to support relevant NIST and CSTL missions. In addition to the primary data collection effort, significant resources have been allocated for data quality assurance for new and existing data in the TRC databases. The panel is impressed with this rapid and efficient transition and now looks forward to efforts to integrate the TRC's staff and projects with the other data collection and evaluation activities of the division.

Membrane Science and Technology

As part of a NIST Advanced Technology Program (ATP), new apparatus has been developed to continue the high-throughput study of membrane transport. This enhanced apparatus, which uses sensitive in-line fluorescence detectors and a fiber-optic multiplexer to provide in situ analysis of eight cells, is in the final testing and demonstration stage. The high-throughput work is relevant for efforts to measure fundamental diffusion and solubility data and to elucidate transport mechanisms. In addition, further work has been done on data measurement systems for pressure-driven membrane separations. With the completion of the ATP work—the major source of funding for the Membrane Science and Technology project in recent years—the panel recommends that division management carefully review whether resources remain to carry forward this project at a level above the critical mass.

Properties for Process Separations

The Properties for Process Separations project recently used its unique experimental capabilities to study the stability of high-temperature organic heat-transfer fluids at the request of the National Renewable Energy Laboratory. These organic heat-transfer fluids, which are used in solar panel electric power generation, must be stable at temperatures to 315 °C and pressure to 4 MPa. Results to date indicate that most of the common hydrocarbon fluids examined are *not* stable as heat-transfer fluids in solar trough applications: other candidate fluids must be developed.

A detailed study that improves the ASTM copper strip corrosion test for sulfur-based impurities in wet liquid petroleum gas (ASTM D-1838) was published and communicated to the appropriate ASTM technical committee. The project's initiative to use in-situ FTIR spectroscopy to collect vapor-liquid equilibria data, particularly on mixtures that are reactive, corrosive, or toxic, has been demonstrated this year by measurements on the test system carbon dioxide + n-butane.

Program Relevance and Effectiveness

The Physical and Chemical Properties Division has continued its excellent efforts to ensure that its technical programs are relevant to the needs of its customers. A variety of mechanisms are used to gather input on current and planned division activities, and suggestions and requests from external organizations are particularly encouraged. Examples of events during which division personnel interact with people from other institutions include standards committee meetings, technical conferences, benchmarking and roadmapping activities, professional society meetings and committees, and trade organization events. Staff take lead roles in organizing these gatherings and often hold them at NIST, as in the case of the 15th Symposium on Thermophysical Properties (discussed below), the International Association for the Properties of Water and Steam Annual Meeting, the Industrial Molecular Simulation Challenge, and the TRC/NIST consortium. Division researchers have informative relationships with a variety of individuals (e.g., guest researchers and collaborators from industry and universities). The panel notes in particular that the balance between work with short- and long-range goals indicates that input from these mechanisms has been and will continue to be effective in helping to set priorities in project selection and continuation.

The panel notes continuing cross-divisional efforts (with the Analytical Chemistry Division) to provide support for the NIST homeland security initiative through the ongoing development of mass spectral methods for the detection of biological weapons. The degree of support for this and other homeland security-related initiatives is unknown until the new Department of Homeland Security is fully organized.

The relevance of division programs is constantly being renewed and refocused through the mechanism of base fund reprogramming, both at the division level and at the CSTL level. Examples of new program directions that were derived from this process in recent years include the creation of the Computational Chemistry Group and the addition of the Thermodynamics Research Center.

As mentioned above, the division maintains excellent balance between shorter-term service-oriented programs and longer-term research programs. Examples of this balance include the following: research to create a mass spectrometry/mass spectroscopy and ion trap library while maintaining and releasing updates to the existing NIST mass spectral library; research on properties and equation-of-state surfaces of fluid mixtures near the critical point while updating property databases such as Version 7.0 of the NIST REFPROP database; and kinetics research on model reactions in ionic liquids while converting the NDRL/NIST kinetics database for free radical reactions in solution to a Web-based and XML-oriented database.

The programs of the Physical and Chemical Properties Division have an impact on a wide array of industries and research communities, in part by bridging the gap between research directed at the often-short-range goals of industry and the long-range, open-ended inquiries commonly pursued in universities. Examples of the value and recognition of division efforts include the receipt by a staff member of the Federal Laboratory Consortium Technology Transfer Award and the notification that the NIST Chemistry WebBook was voted as the winner in the Portals and Information Hubs category of the Best Chemical Sites in a Web contest sponsored by, among others, the U.K Royal Society of Chemistry.

Important products of the division are databases that scientists use to develop computational models and analytical techniques for industrial, environmental, and fundamental chemistry applications. The division is to be commended not only for gathering, evaluating, and maintaining the information necessary to produce these databases but also for performing critical experiments and computations in areas such as gas- and liquid-phase kinetics, thermodynamics, mass spectrometry, and fluid properties in order to provide the data and the underlying understanding that allow the division to make high-quality information readily available to technical communities.

Another area in which the division's work has significant impact is international standards activities, such as the efforts on research related to alternative refrigerants. Division staff are active in a number of organizations on this issue, including the International Energy Agency, International Union for Pure and Applied Chemistry, and ISO. Also, in addition to database products and committee activities, the division provides unique standards and services for fluid flow under cryogenic conditions and SRMs as international standards for calorimetry and thermodynamics.

The division makes strong and well-directed efforts to convey NIST results to the relevant scientific and engineering communities. It effectively utilizes basic tools such as publications and presentations; in FY 2002, 127 papers were published, primarily in peer reviewed journals; 125 presentations (53 invited) were made at scientific meetings; and staff served on 69 national and international scientific committees. The number of citations to research papers, technical reports, and books originating within the division is a potentially useful performance metric.

The breadth of the Physical and Chemical Properties Division's reach into relevant communities can be seen in several other statistics. The Chemistry WebBook was visited from more than 500,000 unique Internet addresses last year (an increase of 43 percent in a year). Roughly one-half of all gas chromatography/mass spectrometry instruments sold worldwide include the Mass Spectral Database. The impact of division research is felt in a variety of ways by different research disciplines, but overall NIST plays a major role in the cross-fertilization of many fields and in integrating the results for the benefit of industrial users throughout the world.

The division has been the primary organizer for the highly successful and visible Symposium on Thermophysical Properties held every 3 years in Boulder. The 15th conference in the series was held June 22-27, 2003. The symposium exemplifies the pivotal role that the division can play in bringing together researchers interested in various aspects of thermophysical properties of fluids.

Division Resources

As of January 2003, staffing for the Physical and Chemical Properties Division included 55 full-time permanent positions, of which 46 were for technical professionals. There were also 16 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The congressionally allocated resources (STRS) made available to the division remain constant or are shrinking. This situation requires division management to obtain additional resources from outside

NIST or from other internal sources or to reallocate existing resources so as to maximize the impact of the remaining programs. Either approach has the potential to affect the quality of the division's work negatively. The percentage of the division's funding received from other government agencies was 21 percent in FY 2002, a slight decrease from FY 2001. The current level is high enough to ensure that NIST work is relevant to external parties. A significant fraction (15 percent) of the current funding arises from sales of the Mass Spectral Database. About 90 percent of the revenue from these sales is returned to the division to maintain this important database. However, other divisional products are currently provided to customers free of charge over the Web—these include the Chemistry WebBook and the chemical kinetics database. The panel continues to recommend that, because the information in these databases is critical to many scientists, NIST should consider imposing a user fee for access, especially since the resources to support the project are limited. Users would likely accept paying a fee in order to guarantee that the databases are current and that they provide increasingly useful features. The panel also notes that more than 95 percent of the income from sales of Standard Reference Databases by NIST is generated by the Physical and Chemical Properties Division.

Although the division continues to sustain excellence in existing experimental and theoretical areas and because of the interest in expanding into emerging computational areas, the panel is concerned that the flat budget does not allow for sufficient new hires to renew and maintain the valuable expertise, thus precluding the division. Continuation of this flat-budget trend will result, in the not-too-distant future, in the loss of sufficient critical mass of expertise, thus precluding meaningful output of the division. The significant and continuing challenge of flat or declining overall resources has been noted at the laboratory level in previous CSTL assessments. The panel is also concerned about the age distribution of researchers within the division; there have been relatively few recent additions of permanent staff at the entry (junior) level.

The staff in Gaithersburg and Boulder are a key asset of the division. The many examples of significant individual accomplishments by staff attest to the high quality of the team of scientists gathered in support of the NIST mission. This quality was demonstrated during the past year by the election of three researchers as fellows of the International Union of Pure and Applied Chemistry. A Department of Commerce Silver Medal was also conferred on a division member. Division personnel are lead editors of two major journals (*International Journal of Chemical Kinetics* and *International Journal of Thermophysics*), editors of the Thermodynamics Research Center Thermodynamic Tables, and associate editors of 18 other publications. These awards and positions of responsibility demonstrate the high regard in which division staff are held by the scientific and industrial communities.

With the recent installation of ventilation hoods and special exhaust systems, satisfactory progress has been made on facilities issues in Building 24 in Boulder. This upgrade is an excellent example of the responsiveness of division and laboratory management to panel feedback and suggestions. However, the panel believes that installation of an elevator must remain a high priority in order to meet current access standards in Building 24; division plans describe this improvement as being of the highest priority. The panel looks forward to progress on the issue in the coming year.

Although adequate to support routine experimental conditions, the exhaust and ventilation systems at the Gaithersburg facilities are still an ongoing concern because of the generally poor air quality in the laboratory and office modules in all of the general-purpose laboratory facilities. The Physical and Chemical Properties Division's laboratories are not among those that will be moved to the nearly completed Advanced Measurement Laboratory, so this issue will not be resolved with the opening of the AML.

In terms of capital equipment, no funding issues appear to limit the initiatives undertaken by division scientists in Gaithersburg or Boulder. In fact, generally, most of the division's range of laboratory equipment exceeds that available in nearly all industrial and academic laboratories.

The panel continues to look for improvement in Web access to the products produced by the division. Coordinated access to the data in the Chemistry WebBook and the TRC database, and indeed a single Web point of entry for access to all chemical data at NIST, are goals acknowledged by the division. With the growing trend away from hard-copy distribution to Web-based distribution of data, there is a need to ensure permanent accessibility by the user community. Because the Physical and Chemical Properties Division generates more than 95 percent of the sales of Standard Reference Databases, the division should take the lead in developing and implementing a strategic plan for NIST to ensure archiving and permanence of the Web-based data distribution systems.

Because of ongoing resource pressures, the panel strongly recommends that the division address the issue of cost recovery for databases in general, possibly through a subscription mode for full access to the data via the Web or through a workable per-retrieval charging mechanism. Current division plans are to develop a proposal by the end of FY 2003 to provide access to the TRC tables via the Web on a fee basis.

Finally, the panel encourages increased use of remote interaction and collaboration tools, such as Web-based audio- and videoconferencing and application sharing. These tools are now available at relatively low cost and have the potential to enhance interactions among researchers in different groups. Some additional investments in hardware and software infrastructure may be necessary for taking full advantage of these tools. Although this is a broader NIST issue, the Physical and Chemical Properties Division is the only NIST division divided between Gaithersburg and Boulder, and it thus stands to gain significant benefits from such tools.

ANALYTICAL CHEMISTRY DIVISION

Technical Merit

The Analytical Chemistry Division (ACD) carries out the following activities:

- Research concerning the qualitative and quantitative determination of chemical composition;
- Development and maintenance of state-of-the-art chemical analysis capabilities;
- Dissemination of tools for measurement traceability and quality assurance (such as reference materials, reference data, and other services); and
- Demonstration of the international comparability of U.S. standards for chemical measurement.

The division serves as the nation's reference laboratory for chemical measurements and standards to enhance U.S. industry's productivity and competitiveness, ensure equity in trade, and provide quality assurance for chemical measurements used for assessing and improving public health, safety, and the environment. The division maintains world-class metrology based on core competencies in analytical mass spectrometry, analytical separation science, atomic and molecular spectroscopy, chemical sensing technology, classical and electroanalytical methods, gas metrology, nuclear analytical methods, and microanalytical technologies.

These core competencies reside in five groups: Spectrochemical Methods, Organic Analytical Methods, Gas Metrology and Classical Methods, Molecular Spectroscopy and Microfluidic Methods, and Nuclear Methods. The skills and knowledge derived from laboratory-based research concerning the phenomena that underpin the measurement of chemical species in a broad spectrum of matrices are continuously applied to the development and critical evaluation of measurement methods of known accuracy and uncertainty. The five primary research groups collaborate in a number of high-priority program areas, including reference methods and standards for clinical diagnostics; measurement standards for forensics and homeland security; measurement methods and standards for nutrients, contaminants, and adulterants in foods; environmental measurements and standards; methods and standards for advanced materials characterization; methods and standards for commodities characterization; and microanalytical technologies (lab-on-a-chip).

The technical merit of the work within ACD has been acknowledged in a number of ways. During this past year, research in the division resulted in 147 peer-reviewed publications, up from an average of 123 per year over the previous 4 years. In addition, two members of the division staff maintained an editorial board membership and an editorship, respectively, with prestigious international journals. The Department of Commerce Bronze Medal for work in visualization methodologies for the communication of complex statistical information was awarded to a division scientist. Finally, the position of the division within the national and international metrology communities is demonstrated by staff participation in 136 scientific committee assignments—an increase from an average of 116 per year over the previous 4 years. Discussions of current division work illustrating technical merit are presented by group in the following sections.

Spectrochemical Methods

Research activities of the Spectrochemical Methods Group continue to set an extremely high standard, and the panel compliments this group for its diligent performance in accordance with the mission of NIST. The various programs associated with mass spectrometry, X-ray fluorescence, optical spectrometry, and sample preparation are proceeding well, and they underscore the productive role that this group plays in creating, developing, and maintaining the SRMs that constitute 71 percent of such products produced by the division. The group has also adapted well to the demands created by new projects aligned to homeland security and the World Trade Center investigation. Furthermore, it continues to show its leadership, relative to other worldwide activities, in all its areas of involvement.

The Spectrochemical Methods Group has a long history of providing research and standards to support environmental measurements regulated by the Clean Water Act of 1972, the Safe Drinking Water Act of 1974, and the Clean Air Act of 1970. A new inductively coupled plasma mass spectrometry method for high-precision comparisons of multielement standards was designed and applied this year to support the quality assurance and proficiency testing programs conducted for the Department of Energy and the Environmental Protection Agency (EPA). This method is capable of yielding 0.2 percent uncertainty for multielement solution standards, and it was applied in the determination of five elements in 13 different mixtures analyzed in support of the EPA-proficiency testing program.

Projects associated with the existence of mercury in the environment continue to deal with one of the most important regulatory concerns, and the group made measurements and certified standards across a range of projects using the recently developed method based on cold-vapor isotope-dilution inductively coupled plasma mass spectrometry. Mercury was determined in a wide variety of SRMs: urine, inorganic sediment, crude oils, pine needles, bovine blood, mussel tissue, fish tissue, and coal.

In the area of air quality, the Spectrochemical Methods Group has been working with the National Institute of Occupational Safety and Health to develop a new series of SRMs: Silica on Filters. Respirable crystalline silica is an occupational hazard whose presence in the workplace is strictly regulated by the Occupational Safety and Health Administration. It is poorly measured by standard industrial techniques (X-ray diffraction, infrared, ultraviolet/visible). Thus, both the demonstration of a safe workplace and effective enforcement of regulations have been frustrated. The new SRMs have been prepared by depositing SRM 1878a, which is certified 100.00 percent ± 0.21 percent crystalline alpha-quartz, on polyvinyl chloride filters.

Organic Analytical Methods

The Organic Analytical Methods Group is responsible for the publication of 44 papers in peer-reviewed journals, 5 NIST special publications, and 62 presentations at national or international scientific meetings, and it issued 10 SRMs. These accomplishments represent an impressive annual record, all the while maintaining high technical quality. This group is quite effective in providing advanced metrology work in its key activity areas and is highly regarded, as attested to by awards received and publications.

Major group activities included measurements and standards in these areas: clinical/health, the environment, food and nutrition, forensics and homeland security, and international comparison studies. STRS activities included development in the five main areas of support based on the major group activity categories. SRM development was completed in each of the major areas: the environment, clinical/health, food and nutrition, and forensics. The clinical/health activity placed an emphasis on in vitro diagnostics with its completion of several SRMs.

Recent research activities in organic mass spectrometry have focused on the development and critical evaluation of new approaches to the quantitative determination of biomolecules (e.g., proteins) in biological matrices. The recent acquisition of a liquid chromatography capability with tandem mass spectrometry (LC/MS/MS) system and a matrix-assisted laser desorption ionization time-of-flight (MALDI-TOF) mass spectrometer has significantly increased the group's capacity for the determination of trace-level analyses of health, nutritional, forensic, and environmental importance, as well as for structural studies of natural products. Recent efforts have been directed toward the development and critical evaluation of reference methods for trooping I (a new marker of myocardial infarction), thyroxin and triiodothreonine (thyroid function), cortisol (a marker for endocrine function), speciated iron (anemia and hemochromatosis), homocysteine (a risk factor for myocardial infarction), folic acid (an essential nutrient that reduces the risks of heart disease and neural tube defects), and prostate-specific antigen for prostate cancer. A particularly timely project currently under way is the development of an ephedrine SRM for both tablet and drink-additive matrices.

The group currently maintains the National Biomonitoring Specimen Bank at two locations, the NIST Gaithersburg campus and the Hollings Marine Laboratory in Charleston, South Carolina. At present, the primary specimen banking activities involve tissues collected from marine mammals throughout the United States, including Alaska, and seabird eggs collected from seabird colonies in Alaska. There are now 2,087 marine mammal tissue specimens banked in the National Biomonitoring Specimen Bank, representing 737 individual animals and 34 species, and 188 seabird eggs from 3 species. These banked specimens represent a resource that has the potential for addressing future issues of marine environmental quality and ecosystem changes through retrospective analyses.

Gas Metrology and Classical Methods

The Gas Metrology and Classical Methods Group is composed of a staff of 17. During the past year, 12 gas mixture standards, 7 conductivity solution standards, 1 anion solution standard, 3 pH materials, and a sodium oxalate reductometric standard were completed. In addition, 42 gas mixture standards were recertified for various clients. The group also worked with five specialty gas companies to develop 35 batches of NIST-Traceable Reference Materials. The more than 1,000 individual gas cylinders comprised by these 35 NTRM batches will be used to produce approximately 100,000 NIST-traceable gas standards for end users worldwide. This work, completed over the preceding calendar year, represents excellent productivity and quality for a technical group of this size.

In work of the Classical Methods team, pH is being ascertained with an uncertainty of 0.0015 to 0.002 pH units using a NIST Harned Cell. This current work has improved NIST primary pH metrology and seeks to relate pH measurement across national laboratories worldwide. Other work includes the development of an absolute conductivity cell for pure water.

Improved analytical tools for real-time measurement of trace-level vapors in the atmosphere are critical for the evaluation of new technologies for reducing hazardous industrial emissions. Toward this end, the group is critically evaluating the capabilities of Fourier Transform microwave spectroscopy for real-time sensing applications. The high spectral resolution and high sensitivity of Fourier transform microwave spectroscopy suggest that the technique can provide unambiguous identification of vapor-phase analytes. The original goal of this project was to address the needs of the automobile industry to identify and quantify trace levels of oxygenates in exhaust emissions. Success in this work will also affect many other critical applications, including the detection of chemical warfare agents.

Molecular Spectroscopy and Microfluidic Methods

The Molecular Spectroscopy and Microfluidic Methods Group conducts research on the metrology of molecular spectroscopy; develops standards for the calibration, validation, and performance of instruments for measuring molecular spectra; and conducts research on microfluidic devices, methods, and applications for chemical analysis, including studies of materials and material properties affecting the flow of liquids in microchannels and the use of microchannel and other electrophoretic methods for forensic and toxicological applications and standards. The group is also responsible for the development and certification of optical transmittance and wavelength standards in the ultraviolet (UV), visible (VIS), and near-infrared (IR) spectral regions; Raman intensity correction standards; and fluorescence wavelength and intensity standards. Finally, the group works with users and manufacturers of analytical instruments to assess and measure the performance of analytical methods and to determine and address existing and future needs for analytical instrument standards ranging from device calibration and instrument performance through specifications for remote device control and data interchange.

This group continues to demonstrate energy, innovation, and exceptional collaborative efforts with other sections and groups at NIST and with institutions and agencies outside NIST. The microfluidics team is particularly active in collaborative efforts and continues to recruit young, promising talent. The program relevance associated with this group's work is exemplified by its certification or recertification of nearly 70 solid absorbance filter SRMs and 202 optical filter sets. Continuing measurements were made on a number of other filter sets. In addition, nearly 250 units of SRM 2034 (holmium oxide UV-VIS wavelength standard) were certified and delivered to the Standard Reference Materials Program. These products are used across a wide spectrum of industry and fulfill an essential requirement.

This year the microfluidics projects resulted in 11 publications, 4 patent applications, and 10 talks and posters. Funding for this area has come from the microscale analytical laboratory's competence award, an ATP intramural grant, a Single Molecule Manipulation and Measurement competence award, and STRS. This program area maintains collaborations with the Process Measurements Division, the Biotechnology Division, the Optical Technology Division, and the Semiconductor Electronics Division. The group continues to attract National Research Council postdoctoral research associates, adding one more this year to bring the group total to four.

In the new competence area of Single Molecule Manipulation and Measurement, several solid accomplishments were achieved. Microchips were developed for the handling of water in fluorocarbon emulsions using optical tweezers; also, protocols were developed for wet chemical bonding of PDMS (polydimethylsiloxane) to PDMS and PDMS to glass. Other protocols developed included those for the production of ultrathin laminated chips with integral capillary ports for high-pressure, low-dead-volume applications, and for a filled loop injector for two-phase fluid systems. The group continued to study the parameters that affect flow in plastic microchannel devices. This past year, major progress was made in applying UV-laser ablation for fabricating microdevices, for studying parameters important to the postmachining properties of microdevices, and for carrying out both physical and chemical modifications to the surfaces of microdevices. There seems little doubt that these studies will have a profound impact on the understanding of microfluidic design in micromachined systems in the future.

Nuclear Methods

Research in the Nuclear Methods Group focuses on the science that supports the identification and quantification of chemical species by nuclear analytical techniques. Current laboratory research activities involve a range of nuclear analytical techniques, including instrumental and radiochemical neutron activation analysis (INAA and RNAA), prompt gamma activation analysis (PGAA), and neutron depth profiling (NDP). In addition, the group is developing further analytical applications of neutron focusing technology. The measurement capabilities within this group provide an excellent complement to those in the Spectrochemical Methods Group, as nuclear analytical methods depend on characteristics of the nucleus of the atom rather than on those of the electron shells, and therefore are insensitive to the chemical state of the analyte (i.e., matrix effects). In addition, the nuclear methods are generally nondestructive and do not require sample dissolution, thus providing an independent assay. NDP and focused beam PGAA provide unique capabilities for the NIST facility in terms of location, sensitive analysis, and elemental mapping.

To develop SRMs for microanalysis, the group has applied new INAA procedures to study the homogeneity of SRMs at small sample sizes. Many analytical techniques used in industry and academia rely on the analysis of very small samples (e.g., 1 mg), typically in the solid (undissolved) form. Unfortunately, most SRMs are certified with minimum sample sizes of 100 to 500 mg, and they are therefore unsuitable for use as control materials for these techniques unless additional information is made available. Taking advantage of the sensitivity and nondestructive properties of INAA, the use of this technique for homogeneity studies of small samples has been evaluated and implemented for the determination of sampling characteristics for a number of environmental SRMs. The small analytical uncertainty associated with the INAA measurements allows extraction of the variability due to material inhomogeneity from the observed total variability within a given set of measurements.

A good deal of this past year's effort has coincidentally involved materials of interest in advanced energy systems. A method has been developed and an apparatus built to produce titanium (and other metal) SRMs of known hydrogen concentration on the scale of a few kilograms. After preparation, the hydrogen concentration is verified by cold-neutron PGAA and gravimetry. This apparatus has also been used to prepare standards for the neutron-tomographic nondestructive analysis of turbine blades at McClellan Air Force Base.

Current experiments of interest at the NDP instrument include the measurement of lithium concentration and distribution in thin films being studied for battery applications, studies of boron mobility in tungsten with the Army Research Laboratory, studies of shallow-doped boron content in silicon in conjunction with Advanced Micro Devices, the study of lithium distribution in lithium niobate, and the measurement of nitrogen in layers such as TiN and GaN. As a recent example, NDP has been used to measure nitrogen distributions in GaN/GaAs bilayers with Corning. This material is a base material for the construction of devices such as blue, light-emitting lasers. The nitrogen concentration is a crucial parameter for establishing the device characteristics. Nitrogen concentrations of MnN/ScN have been determined in conjunction with scientists from the NIST Center for Neutron Research and Ohio University. MnN is a metallic antiferromagnetic material that can be used with ferromagnetic semiconductors to make spintronic devices for data storage systems.

In addition to the collaborations highlighted above, staff in the Nuclear Methods Group have also worked on a number of high-priority projects with more than 20 other "outside clients" as part of their responsibility for supporting the NIST Center for Neutron Research National Users' Facility. Many of the current PGAA collaborations involve determining hydrogen in a wide variety of materials for different applications. For example, the group is currently collaborating with Jefferson Laboratory to monitor the hydrogen content of niobium that was used in the construction of the accelerator for the Spallation Neutron Source at Oak Ridge National Laboratory. PGAA has also been used to determine the hydrogen content of carbon nanotubes (a potential hydrogen storage material) and to study hydrogen uptake by solid proton conductors of formula $BaPr_{1-x}Y_xO_3$ for fuel cell applications. Other measurements made at the PGAA facility this year include H, S, Ca, and K in Nafions, which have potential use as membranes in electrochemical separations and in fuel cells.

Program Relevance and Effectiveness

The issue of identity and differentiation is an important one for the Analytical Chemistry Division. Among the ever-expanding number and complexity of sensors and measurement devices throughout the nation, one unique capability of this division is not duplicated anywhere in the United States. This is the critical function of developing SRMs and concurrent technologies that provide exacting performance for highly repeatable, accurate, and reproducible measurements. The objective of the division is not preeminence in research to develop new measurement technologies, but rather the perfection of these technologies using specialized analytical metrology expertise. The expertise of the division should be applied to improve newer technologies into accurate, traceable, and reproducible measurements. These functions clearly differentiate the essential value of the Analytical Chemistry Division over other national laboratories, industrial research, and university skill sets.

Increased requirements for quality of systems documentation for trade and effective decision making regarding the health and safety of the U.S. population have increased the need for demonstrating traceability to NIST measurements and standards and establishing a more formal means for documenting measurement comparability with standards laboratories of other nations and/or regions. SRMs are certified reference materials issued under the National Institute of Standards and Technology trademark that are well characterized using state-of-the-art measurement methods and/or technologies for chemical composition and/or physical properties. Traditionally, SRMs have been the primary tools that NIST provides to the user community for achieving chemical measurement quality assurance and traceability to national standards.

The division provides traceability of chemical measurements used in programs of national and international importance through SRMs, NIST-Traceable Reference Materials (NTRMs), measurement quality assurance programs in critical areas, and comparisons of NIST chemical measurement capabilities and standards with those of other National Metrology Institutes. Examples demonstrating program relevance and effectiveness follow.

The NTRM program was created to partially address the problem of increasing requirements for reference materials with a well-defined linkage to national standards. An NTRM is a commercially produced reference material with a well-defined traceability linkage to existing NIST standards for chemical measurements. This traceability linkage is established via criteria and protocols defined by NIST and tailored to meet the needs of the metrology community to be served. The NTRM concept was implemented initially in the gas standards area to allow NIST to respond to increasing demands for high-quality reference materials needed to implement the emissions-trading provisions of the Clean Air Act of 1970 (while facing the fact that human and financial resources have not been increasing at NIST). The program has been highly successful. Since its inception, 12 specialty gas companies have worked with NIST to certify more than 9,000 NTRM cylinders of gas mixtures that have been used to produce more than 500,000 NIST-traceable gas standards. A recent study conducted by RTI International estimates that the net benefits of the NTRM program projected through 2007 will be between $50 million and $63 million, with a social rate of return of about 225 percent.

International agreements and decisions concerning trade and our social well-being are increasingly calling upon mutual recognition of measurements and tests between nations. The absence of such mutual recognition is considered to be a technical barrier to trade, environmental, and health-related decision making. In recent years, mutual recognition agreements have been established related to testing and calibration services and with respect to the bodies accrediting such activities. The Analytical Chemistry Division has taken a leadership role on the International Committee of Weights and Measures-Consultative Committee on the Quantity of Material (CCQM) and the Chemical Metrology Working Group of the Inter-American System for Metrology (SIM) in order to ensure the effective, fair, and metrologically sound implementation of this mutual recognition agreement. Division staff members are leading various activities within CCQM and chairing the Organic Analysis Working Group. During the past 5 years, 53 comparison studies have been conducted under the auspices of the CCQM. The Analytical Chemistry Division has participated in 46 of these, serving as pilot laboratory in 18. An additional 36 studies are planned to be conducted over the next 3 years, and NIST has committed to pilot 9 of them.

Providing chemical measurement quality assurance services in support of other federal and state government agency programs (on a cost-reimbursable basis) continues to be an important part of the division's measurement service delivery portfolio. During the past year, the Analytical Chemistry Division was involved in 25 projects with 11 federal and state government agencies. The division also had technical interactions that involved laboratory research and measurement activities with more than 20 professional organizations and societies, including the American Industry/Government Emissions Research (AIGER) consortium, American Association for Clinical Chemistry, American Society for Testing and Materials, Certified Reference Materials Manufacturers Association, National Food Processors Association, National Council on Clinical Chemistry, and the National Environmental Laboratory Accreditation Council. Specific details concerning many of these interactions are provided below.

Other high-priority efforts are directed at the detection of various poison agents in food, water, or air that might be used less for mass destruction and more for mass terror. Thus, the ongoing efforts to benchmark the detection of trace elements and the characterization of "natural" levels of elements in the environment, body fluids, and in our foods take on increased relevance. The division has added new certified values for Cd and Hg in the blood SRM 966 at concentrations of a few tens of parts per trillion and has completed analyses for a suite of toxic elements in the urine SRM 2670a at levels as low as 5 parts per trillion.

NIST works with other government agencies, professional organizations, the private sector, and the international community through the recently formed Joint Committee on Traceability in Laboratory Medicine to prioritize measurement and standards needs.

In addition to the clinical measurement reliability and cost issues that have driven measurement and standards for the clinical diagnostic markers project over the past 20 years, a very significant commerce and competitiveness issue has recently emerged—the European Directive 98/79/EC on in vitro diagnostic (IVD) medical devices. By December 2003, manufacturers must declare that any new IVD product to be sold within the European Union complies with all the "essential requirements" of this directive. One of these requirements is that IVD products be traceable to "standards of the highest order"—for example, nationally and/or internationally recognized reference methods and/or certified reference materials. At present, IVD devices are used in clinical laboratories to measure more than 300 different chemical or biochemical species. Reference methods and/or materials exist for about 30 of these. Approximately 60 percent of the IVD products currently on the European market are imported from the United States. Excluding home diagnostics, the overall worldwide IVD market is an approximately $20 billion market.

Over the next decade, driven by the availability of new sensor-based measurement technologies, more and more clinical testing will be done outside the traditional clinical laboratory. The annual U.S. market alone for this new form of clinical measurements, called point-of-care testing (POCT), is currently a billion-dollar market, growing at an annual rate of 10 percent. POCT is expected to be used extensively in the home as part of a self-care trend, which is currently experiencing a 70 percent growth rate. Published studies have concluded that POCT provides at least the same level of diagnostic value as centralized testing, but at half the cost. The standards infrastructure that has supported clinical chemistry for the past two decades must adapt to support POCT. Collaborative efforts need to be established among national standards laboratories, IVD manufacturers, and others in the medical professional community to develop appropriate technologies and nonbiohazardous standards to facilitate the provision of data for medical decision making that are accurate and traceable to national/international standards. NIST leadership in developing traceable POCT standards will help ensure continued U.S. dominance of the worldwide IVD market and foster more affordable health care both at home and abroad.

The main directive to the Gas Metrology team is to produce universally available large-volume traceable mixtures. The primary standards are actually prepared at the NIST facilities in Gaithersburg. The requirements for new standards are determined based on inputs from the U.S. EPA, automobile manufacturers, specialty gas manufacturers, the AIGER consortium, and others. The team seeks to respond to regulatory and industry needs while maintaining world-class excellence in gas metrology. In response to AIGER's request, low-level NO (nitrogen monoxide) in nitrogen mixtures was provided. Specialized techniques were developed to condition aluminum cylinders to make them capable of holding such a mixture at stable conditions for extended periods. The team continues to interact with industry and regulatory groups, such as the California Air Resource Board and the EPA, in efforts to provide accurate standards for stack gas and automobile emissions measurements. The team is looking for industrial partners to work with in producing low-volume standards, which do not require SRM status. It seeks to be responsive to customer needs while managing the effort with limited resources.

The Gas Metrology and Classical Methods Group has continued its collaboration with the EPA and the remote-sensing community in the development of a quantitative database of IR spectra for the calibration of IR-based technology used for real-time monitoring of airborne chemical contaminants along plant boundaries and within plant facilities. The spectra are being prepared using NIST primary gas standards. These standards have been critically evaluated at NIST and intercompared internationally. The use of SRD-79 to establish the traceability of open-path IR measurements will be required in the update of EPA method TO-16. SRD-79 currently has data for 40 compounds.

The group also continues to support U.S. industry through the development and dissemination of high-priority reference materials on the basis of input from organizations such as the AIGER consortium and ASTM. Over the past 2 years, two new low-concentration nitric oxide gas SRMs have been developed. These SRMs are needed by the automotive industry in the development of new cars and to meet new regulations in California. These standards are also required by industry to meet new regulations covering stack gas emissions. These gas SRMs, one at 0.5 ppm (SRM 2737) and one at 1.0 ppm

(SRM 2738), will be available for sale late in FY 2003. They are the result of an active collaboration between NIST and the AIGER consortium, which donated the candidate gas mixtures for the SRM. This work also involved collaboration with the Scott Specialty Gases Company to develop the technology used in passivating the cylinders.

Interactive activities of the Molecular Spectrometry and Microfluidic Methods Group during the past year included measurements for the SIM intercomparison of holmium oxide solutions for the completed UV/VIS wavelength standards. Report preparation is under way. The report of the similar North American Metrology Organization study was published in *Analytical Chemistry*, and the results were used to establish new uncertainty values for the wavelength assignments of SRM 2034, Holmium Oxide Solution. To this end, it has been proposed that the spectrum of holmium oxide may be useful as an "intrinsic" standard—a standard whose purity can be assessed inherently and whose wavelength "peak" values at given spectral slit widths can be certified independently and published as standard reference data. Therefore, a given artifact, independent of source, can be accurately assessed and, if found suitable, can be utilized as a standard. To substantiate this concept, it is necessary to assess the extent of the international agreement on the wavelength assignments for holmium oxide solutions. Accordingly, this group has begun a holmium oxide wavelength intercomparison with several NMIs around the world. If this concept proves correct, the wavelength values as a function of spectral slit width will be published as a Standard Reference Database.

The Molecular Spectroscopy and Microfluidic Methods Group continues to provide statistics and data representation studies for the FBI, the NIST Office of Law Enforcement Standards, and other agencies investigating the use of DNA methods of forensic analysis. In close collaboration with the CSTL Biotechnology Division, significant progress has been made on three projects: the Armed Forces DNA Identification Laboratory-sponsored study of DNA extractability from archival media was completed and the final report published; data entry and validation for the OLES-sponsored Mixed Stain Study #3 interlaboratory challenge exercise has been completed; and database and quality assurance procedures have been (and are being) developed for the Biotechnology Division's Y-STR databank, sponsored by the National Institute of Justice.

Division Resources

The Analytical Chemistry Division had approximately 90 scientists, technicians, and administrative/clerical support staff as of January 2003. The division has an annual budget of about $15 million, of which about $6 million supports programs for other federal and state government agencies and/or U.S. industry on a cost-reimbursable basis.

Most of the funding sources have been relatively constant over the FY 1998-2003 period, with the STRS base funding increasing at a reasonable rate. The greatest variability over the past few years has been in the working capital fund derived from the SRM program.

Over the past 4 years, there has been a steady decrease in personnel, specifically in the permanent and term professional categories. Unlike in previous years, a formal reduction in force (RIF) was undertaken this year based on budgetary concerns; the positions of four permanent professionals and one technician were eliminated. RIFs in scientific personnel have a particularly profound effect in this division, which has a very high service load with regard to the SRM program and international activities.

It should be stated that part of the budget pressure experienced by this division is a direct consequence of needing to place priorities on the purchases of modern instrumentation that had long been delayed. For example, as pointed out in last year's assessment report, the lack of an inductively coupled plasma mass spectrometry system having collision cell capabilities was a glaring shortcoming. This and other purchases were made this year, at the partial expense of personnel. While these purchases are key to the performance of the division, the situation of having to choose between personnel and the tools necessary to carry out the mission of the division is disturbing. The successful operation of the division should be of concern at all levels of NIST, as the potential impact on U.S. industry is enormous.

Given the financial difficulties of the past year, and particularly considering the RIF, the mood of the staff present at the skip-session (with no management present) was better than expected. Clearly there was a feeling of having to continue to do more with less. The staff members are extremely positive as suggested in their comments regarding the opportunities and the working environment at NIST, but they do express concern about the growing difficulty in replacing equipment or maintaining the scientific leadership position that they have come to expect. International cooperation was felt by staff to be beneficial; however, some commented that competition with other NMIs is not all positive: “Our interaction has been more of form or politically oriented than scientific results-oriented.” It was felt by staff members that the division, while highly touted in CSTL and NIST reports, did not receive in-kind recognition internally through financial support of the programs. In short, they felt that the division as a whole was not valued, as exhibited through underrepresentation in exploratory research funding and from its being the sole division experiencing a RIF during the year. Interestingly, they did understand that division-level decisions regarding personnel and instrumentation purchases were not independent of one another. There was also concern expressed about a shortage of staff to maintain the SRM programs that generate significant revenue for NIST. Many comments were made relative to the leadership and communication skills of group leaders. As in previous years, communication relative to the budgeting process was noted as a shortcoming. On the other hand, the methods of setting priorities did seem to be well elucidated by the division leadership. In general, though, the vast majority of the staff in attendance at the skip-level session indicated that NIST and the Analytical Chemistry Division are very good places to work.

The panel is concerned over the potential loss of expertise in some technical areas: in glass mixing, cutting, and polishing with the high precision required for SRMs and in precision machining for SRM quality fixtures. It is the panel’s understanding that glasswork is contracted to former NIST employees, now retired, with some 70-plus combined years of NIST glasswork experience relative to SRMs. There is not a sufficient effort to replace this expertise with younger trainees. Secondly, the precise machine shops must operate in a nonsubsidized manner, placing pressure on the future existence of this function and expertise within NIST. With the world-class skill levels required in the manufacturing of quality SRMs, neglect of these functions could seriously jeopardize future SRM quality or costs of production. These important support services are considered to be of vital interest to CSTL as a whole.

Recommendations

Given the critical positioning of the Analytical Chemistry Division as the primary laboratory for the development and certification of an appreciable fraction of the NIST SRM portfolio, it is imperative that the division maintain the highest quality of personnel and instrumentation available in the United States. As demonstrated through the division’s international activities, its participation and capabilities are crucial to the competitiveness of U.S. industries. The program directed at in vitro diagnostics is an excellent example. The RIF this year reflects strains on the organization in terms of making decisions between keeping highly skilled employees and maintaining state-of-the-art capabilities in supporting instrumentation. Clearly, given the charter of the division, this either/or situation cannot be tolerated, as both productivity and quality will suffer. The laboratory is encouraged to evaluate the real costs of SRM development and recertification, keeping in mind that both of these activities are de facto more expensive in terms of personnel and instrumentation costs than is reflected in the current SRM pricing and cost reimbursement. As an example of pricing disparities, a comparison of the cost of a NIST aluminum alloy SRM and a commercial aluminum Certified Reference Material (CRM) product reveals that the SRM costs approximately one-half the price of the commercial CRM. Clearly, this does not reflect the quality of SRMs and the supporting infrastructure required to maintain world leadership in standard materials. It is further suggested that unlike the situation with the current structure of the working fund, such projects have a nominal surcharge that is assessed specifically for instrument purchases that can in fact be accessed at the front end of projects (if needed).

The division should begin to plan for major personnel changes in the Nuclear Methods Group. While there is no apparent immediate need in this area, it is clear from the demographics of that group that the vast majority of its scientists might take retirement over a limited time frame. Plans should be made for training potential replacement scientists as well as for developing new leadership within the group. Given the highly specialized nature of this group, there is not expected to be a large, young, talent pool, so the challenge will be great.

The direction of standards development and basic research naturally evolves over time. In many respects, the success of the microfluidics effort in the Molecular Spectroscopy and Microfluidic Methods Group has resulted in the creation of a very strong subgroup that is reasonably distinct from the remainder of the program. In fact, this subgroup addresses a long-standing shortcoming in the area of microanalytics. Clearly, the impact of micro-total analysis systems as its own subdiscipline within analytical chemistry is felt in many industrial sectors and is worthy of more serious attention by NIST in general, and not only through aspects of microfluidics. Perhaps a realignment of the groups in terms of elemental/inorganic analysis, organic analysis, molecular spectrometry, gas metrology and classical methods, and a new microanalytics group, may make sense. A microanalytics group would in many respects contain aspects of the other groups, but such a change would allow a focus specifically on analytical systems (i.e., a systems approach) and reference materials as they pertain to the ever-broadening scope of micro-total analysis systems.

The participation of division staff in international comparison activities is seen as a vital function. At present, staff limitations could eventually begin to place limits on the necessary activities. In addition to the time required to perform comparisons, report generation and travel also place demands on time and other resources. Finally, efforts are also required in the mentoring of staff of other NMIs not having the skill sets of the division scientists. To recoup these costs requires some specific mechanism other than the standard operating budget, which does not account for these activities in terms of personnel time and other direct costs.

The activities related to homeland security are progressing well. Other opportunities may exist, in collaboration with the Transportation and Security Administration (TSA)—possibly in the areas of methodology standardization, performance assessment, and reference material development. It may be that TSA is performing such services in-house, but these activities would certainly be appropriate for and well performed by the Analytical Chemistry Division. Such opportunities should be investigated.

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Physics Laboratory: Division Reviews

ELECTRON AND OPTICAL PHYSICS DIVISION

Technical Merit

The Electron and Optical Physics Division develops measurement capabilities needed by emerging electronic and optical technologies, especially those required for submicrometer fabrication, characterization, and analysis. The division consists of three groups: Photon Physics, Far UV Physics, and Electron Physics. During its assessment the panel found that the technical quality of the division's work continued at a very high level, leading to important advances in several areas. Discussion of the technical quality of ongoing work for each of the groups is presented below.

Photon Physics

The Synchrotron Ultraviolet Radiation Facility (SURF III) has now been operational for a year since its most recent upgrade. Emphasis has been placed on work in the extreme ultraviolet (EUV) spectral region. Because of the ready availability of stable, debris-free radiation in this wavelength range, the SURF III facility is well suited for this work. Such work is of major importance to the semiconductor community, since EUV lithography is the leading candidate for next-generation lithography technology.

This past year, the group participated in an EUV mirror reflectometry study that compared the measurement results from five different facilities. It was found that the NIST EUV monochromator exhibits poor wavelength control owing to mechanical instabilities. An upgrade has been initiated for this monochromator at a cost of approximately $250,000. This expense is justified, since EUV mirror

NOTE: Chapter 5, "Physics Laboratory," which presents the laboratory-level review, includes a chart showing the laboratory's organizational structure (Figure 5.1) and a table indicating its sources of funding (Table 5.1).

testing will continue to be an important function provided by NIST as the EUV lithography market begins to grow. Once this capital improvement is complete, NIST should be in a position to provide this measurement service, for a fee, to industry.

A second important characteristic of EUV mirrors is their lifetime under exposure. At the beginning of last year, an EUV mirror lifetime test capability was being constructed. At that time it was suggested by the review panel that NIST pursue funding for this lifetime testing, since its facility was uniquely qualified for such long-term lifetime testing under controlled conditions. It has done so and received some nominal fees from parties interested in improving the reflectivity lifetime of EUV mirrors. This lifetime testing is very critical to the success of the EUV lithography market. This work should be continued and expanded, and additional external funding should be pursued.

Another area of strength for the Photon Physics Group is in the calibration of EUV detectors. Understanding not only the performance of EUV detectors, but also the entire method and apparatus for selecting out the 13.5-nm radiation band of interest for lithography is important for this industry. At the present time, many different methods are used to select the desired 13.5-nm radiation for measurement. Each method has its strengths and weaknesses. Understanding these issues and providing this information to the EUV lithography community fit well within the NIST charter. In addition, NIST can provide the neutral-party evaluation of these methods that is needed for improving the ability to compare results from different EUV source vendors and users.

The Photon Physics Group made progress during the past year toward creating a world-class EUV radiation facility. Knowledge of this group's capabilities among researchers in the field, both at public institutions and in private industry, should be promoted more aggressively.

Far UV Physics

The Far UV Physics Group operates, maintains, and continues to improve the SURF III synchrotron light source. Activities at SURF III are becoming more and more focused on radiometry in the ultraviolet, serving the lithography community. As the critical dimensions of electronic devices become shorter, the wavelengths required for lithography move into the UV and EUV, such as the laser lines at 193 nm and 157 nm and the multilayer EUV wavelength of 13 nm. SURF III can play a unique role in the United States by providing an absolute calibration standard for these wavelengths. Comparison measurements have been made at similar institutions abroad, such as the Physikalisch-Technische Bundesanstalt in Germany. At present, U.S. researchers are sending their detectors to these foreign laboratories for calibration. This NIST facility is equally qualified for such work and should pursue all practical opportunities. The facility and its beam lines have undergone a continuous series of upgrades and are now better by far than originally designed.

A new beam line has become operational (Beam line 3), providing an absolute radiation standard by tracing the light intensity to that of a single electron, which is calculable from first principles. An array of photodiodes brackets the large dynamic range between few electrons and a normal beam current (up to 1 A, an increase by an order of magnitude over the past few years and an amazing feat for such a low-energy storage ring). A second radiometry beam line features a cryogenic detector that provides an absolute standard for detectors (Beam line 4). A widely used product is the calibration of diodes as secondary standards, which entails painstaking measurements of aging effects and development of diode coatings, such as platinum silicide, for better stability.

A UV interferometer beam line is also serving the lithography community by high-precision measurements of optical constants. These are required for the demanding specifications of CaF_2 optics for excimer laser lithography. Measurements are under way that are relevant to immersion lenses, which might be able to extend the use of optical lithography by one more device generation.

On the machine side, an RF upgrade has now been completed that provides a stable beam up to the full current of 1 A and a high degree of control over the beam shape and lifetime.

A donated photoelectron microscope is currently being retrofitted and tested with a UV lamp. It allows imaging of the work function distribution across a surface. It has been used previously for imaging chemical reactions at surfaces. It would be interesting to explore whether this technique can be used for imaging radiation damage on diodes and optical elements. Owing to its low beam energy, SURF III is well suited for providing photons with energies in the typical range of work functions (3 to 5 eV).

Electron Physics

The Electron Physics Group is an internationally recognized leader in the development of innovative measurement tools and techniques, harnessing them to address fundamental challenges at the forefront of nanoscale science and technology. The Nanoscale Physics Laboratory constructed by the group is composed of a scanning tunneling microscope (STM) combined with two molecular beam epitaxy units and a field ion microscope for tip preparation. A fixed-direction magnetic field as large as 10 tesla (T) or a variable-orientation field up to 1.5 T can be applied to a sample. The system can operate at temperatures as low as 2 K. This unique facility will enable the group to maintain its leadership position in the synthesis and characterization of nanostructured materials. Recent research includes the first real-space measurement of the magnetic field-induced hexagonal-to-square transition in the vortex lattice structure of the superconducting compound V_3Si. Work is also proceeding on the autonomous atom assembly project mentioned in last year's report. The goal is atom-by-atom fabrication of quantum structures. Current attention is directed toward perfecting the control software and optimizing the parameters for tunneling manipulation.

Significant progress has been made in the "atom on demand" effort, which involves capturing single atoms in a magneto-optical trap and moving them with lasers. A high-power CO_2 laser has been acquired for use as "tweezers" to extract atoms from the source. The next steps are to assess the viability of this approach and then to place atoms into specific magnetic traps. One tantalizing objective is to create architectures for quantum computing.

As reported last year, one goal of the Scanning Electron Microscopy with Polarization Analysis (SEMPA) project is 10-nm image resolution of magnetic structures such as hard disk storage media. Although the field emission scanning electron microscope acquired for this purpose continues to function at 25-nm resolution, attainment of the 10-nm scale remains elusive because of the vendor's inability to meet specifications. The existing capability is being used to image various patterned nanostructures and to investigate the behavior of thin magnetic films (e.g., Fe on a GaAs substrate). Additionally, work with the Naval Research Laboratory (NRL) is being initiated to analyze real-time operation of spintronic devices such as sensors.

A theoretical effort effectively complements the experimental work of the Electron Physics Group by serving as a catalyst for new ideas and providing a valuable resource for problem solving. Internal as well as external interactions have been established. An example of the former is analytical work on vortex states in V_3Si to assist the Nanoscale Physics Laboratory's measurements, while among the latter are a collaboration with Nanoscale Physics Laboratory on spin injection from a ferromagnetic metal into a semiconductor and work with researchers at the Georgia Institute of Technology and the Johns Hopkins University addressing spin-transfer torques in magnetic heterostructures.

Program Relevance and Effectiveness

A wide variety of organizations have great interest in the expertise and capabilities of the Electron and Optical Physics Division. Customers of the Photon Physics and Far UV Physics Groups include corporations as well as government agencies and laboratories that need calibration standards for radiometry. Typical products are diodes as secondary standards; calibration of the exposure of photoresists, which becomes more and more critical with high-contrast resists; calibration of (multilayer) optics; and calibration of charge-coupled detectors.

The ongoing, cutting-edge research of the Electron Physics Group in nanoscale science and technology is relevant to a broad spectrum of industrial, academic, and government customers. Many companies await the high-resolution SEMPA capability being pursued in the group. The Nanoscale Physics Laboratory will undoubtedly stimulate customer interest in several areas, such as single-atom manipulation for device structure fabrication and quantum computing. The "atom on demand" work has potential applications in quantum information processing and modulated doping.

Technical results are communicated to customers in various ways—among them, direct interactions, presentations at conferences, and reports. Division researchers continue to publish a significant number of high-quality papers in the refereed scientific literature, satisfying the panel's expectation in the previous report. The panel strongly encourages the division to maintain this important form of participation in the activities of the external scientific community.

Division Resources

The panel is concerned that funding for overhead functions in the Electron and Optical Physics Division seems to be getting more limited. It is recognized, however, that many of the limitations were created by external mandates imposed after the terrorist attacks of September 11, 2001. Significant start-up problems with the use of electronic forms (e.g., pay for performance) were also noted by the staff.

Division morale remains high, and staff members shared in several awards during the past year. The recent Nobel Prizes won by NIST scientists continue to stimulate intellectual excitement and enthusiasm.

ATOMIC PHYSICS DIVISION

Technical Merit

The Atomic Physics Division develops and applies atomic physics research methods to achieve fundamental advances in measurement science and to produce and critically compile physical reference data. The division is organized in five groups: Plasma Radiation, Quantum Processes, Laser Cooling and Trapping, Atomic Spectroscopy, and Quantum Metrology. The panel is very favorably impressed with the excellent performance of the division in achieving its mission. The following subsections provide examples of ongoing work in each group and present discussions illustrating its quality and high level of importance to scientific and industrial communities.

Plasma Radiation

Among other things, the Plasma Radiation Group operates the laboratory's electron-beam ion trap (EBIT). The NIST EBIT is a unique, well-characterized facility that allows fundamental studies of a variety of processes with highly charged ions for both fundamental science and its applications. This facility allows studies that make unique and important contributions on a wide variety of topics, and the group continues to be a leader in studies of the fundamental properties of highly charged ions. The EBIT effort is divided into two parts: in-trap studies (UV/X-ray spectroscopy) and surface studies.

Of particular note this year are the charge exchange studies that the group performed using its new gas jet target.

The group's expertise in surface modification by highly charged ions has led to its playing a pivotal role in the characterization of damage to light-collection optics for EUV lithography by highly charged xenon ions.

The group is also successfully pursuing properties of optical materials at the 157-nm wavelength using optical measurements. These properties are of importance to future-generation vacuum ultraviolet (VUV) lithography for integrated circuits. The group not only has discovered the original birefringence phenomenon but also has generated the new concepts that are required for the development of new hybrid materials, to avoid the problem. This effort has resulted in substantial outside recognition for the Physics Laboratory.

The Gaseous Electronics Conference (GEC) reference cell work on submillimeter spectroscopy of processing plasmas is demonstrating its importance for understanding the influence of important trace components in mixtures at very low concentrations.

Quantum Processes

The Quantum Processes Group is one of the few theoretical atomic, molecular, and optical (AMO) physics groups in the United States; as such, it is a national resource and leader in the U.S. theoretical AMO community. Theoretical advances of the group support a variety of experimental efforts, such as clocks, quantum degenerate gases, quantum dots, single-molecule detection, and quantum information. A distinguishing mark of the group is its emphasis on realistic models of the processes it is studying, and for this reason it is often able to confront experimental information in meaningful ways. Over the years, the group has developed a number of numerical codes and successfully applied them to a wide variety of physical, chemical, and optical phenomena. It plays an important leadership role in the NIST Quantum Information initiative.

The Quantum Processes Group is very productive and has made a number of significant advances during the past year. Examples of note to the panel are the recent demonstration of Bose condensate in Cs gas, new work on coherent manipulation of collisions in Bose-Einstein condensates (BECs) that permits new insights into the production of ultracold molecules, and new concepts for neutral-atom quantum computing. The group continues to supply absolutely essential theoretical support for many activities of the Laser Cooling Group and is advancing the state of the art of simulation of quantum dots.

Laser Cooling and Trapping

The Laser Cooling and Trapping Group is pursuing a large number of cutting-edge experiments in atomic and quantum physics. Experiments under way include a variety of experiments on Na and Rb BECs, in particular, studies of superlattices that are proving to be extremely interesting and fruitful. Other experiments include studies of ultracold photoassociation in coherent and incoherent atomic samples as well as studies of ultracold plasmas that are leading the field. The group is internationally recognized for its excellence and leadership in an extremely competitive and productive field of research. It is a national treasure that should continue to be nurtured by NIST.

Atomic Spectroscopy

The Atomic Spectroscopy Group is the primary center in the world for critically evaluating, compiling, and disseminating basic atomic spectroscopic data as well as fundamental physical constants. It also provides highly accurate laboratory measurements and theoretical computational tools in response to the individual needs of customers who commission such work. The work done to meet such customer needs often leads to improvements in knowledge of the structure and spectroscopic properties of atoms and ions that ultimately have broader applications beyond those originally envisioned. In these roles, the group provides essential measurement standards support for the national scientific, industrial, and government infrastructure. Its reputation for data accuracy and integrity, earned over many decades, makes the group a unique and irreplaceable resource on which many important constituencies around the world rely.

Quantum Metrology

Currently, the Quantum Metrology Group has a somewhat narrow focus compared with that of years past (driven by lack of staff, which is discussed below), with its primary areas of work in precision optical metrology, precision X-ray spectroscopy, and advanced X-ray measurements. These activities are world-class in caliber, clearly support the core function of NIST, and should be appropriately supported.

Program Relevance and Effectiveness

Programs in the Atomic Physics Division show a clear tracking to the NIST mission in both relevance and effectiveness. The level of support offered by the division's work to national industrial and scientific endeavors can be illustrated by several examples. The laboratory's EBIT team has established itself as a key leader in many scientific and technological challenges facing EUV lithography. It has capabilities that allow it to address important issues for astrophysics and for the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory. The group has been aggressive in establishing externally funded, high-visibility partnerships with SEMATECH, Intel, NIF, NASA, and the Harvard-Smithsonian Center for Astrophysics. The group has admirably focused its efforts to meet these exciting challenges. Of particular note here is that all aspects of the EBIT effort, the spectroscopy and collision studies of highly charged ions, and the surface modification capabilities are coherently contributing to these partnerships.

The GEC reference cell work is now focusing on submillimeter absorption spectroscopy diagnostics for plasma processing. The technique provides high spectral resolution over a wide spectral range. It is used to monitor plasma temperatures, composition, and concentrations. This effort is strongly focused toward supporting industrial needs. The plasma radiation researchers have in particular established a fruitful relationship with Air Products Corporation.

The VUV lithography effort has been extraordinarily productive, in terms of both advancing basic science and addressing key issues for industry. The precision studies of birefringence over the past few years have led to remarkable progress toward the very serious VUV materials problems. This work has led to well-deserved and substantial outside recognition for the NIST Physics Laboratory.

Fundamental and applied AMO science efforts strongly overlap with the NIST core measurement and metrology functions. For example, theoretical work in quantum information is directly impacting advances in quantum measurements of great importance to standards.

Work in laser cooling and quantum processes is more strongly oriented toward basic research than are most other activities at NIST. However, the research directions chosen anticipate, within reason, key long-term national measurement needs. Just as earlier studies of optical "molasses" have contributed to the international time standard's being based on laser cooling technology, so the current efforts on quantum degenerate gases will likely have impacts on precision measurements, quantum computing, and clocks.

The Atomic Spectroscopy Group has in the past few years successfully made the transition to computer and Web-based data compilation and dissemination tools, providing major improvements in the accessibility and ease of use of the data compilations. These changes have also enabled the more rapid updating of critically evaluated data sets, giving consumers confidence that they always have available the most current and accurate values of the data needed for their applications. For example, the fundamental physical constants previously had been updated about once every 13 years. With the release during the summer of 2003 of a fully revised version, the group will have succeeded in meeting its goal of an update every 4 years. Over the past 2 years, Internet requests for atomic spectroscopic data of all kinds have grown from an average of about 64,000 per month in calendar year 2000 to more than 94,000 per month in 2002. Internet requests for fundamental constants data averaged about 130,000 per month in 2002. Significant funded "commissions" for precise laboratory spectroscopic and other measurements were received from NASA, the European Space Agency, DOE, and the Electric Power Research Institute. It is clear that the Atomic Spectroscopy Group is serving the critical needs of a variety of constituencies exceedingly well.

One particularly impressive theme being addressed across disciplines within the Atomic Physics Division is the support of initiatives of the microlithography industry toward significantly higher circuit densities in microelectronics. Laser lithography is rapidly evolving in the use of deep ultraviolet, and now EUV, laser light sources. The Atomic Spectroscopy Group's laboratory provided precise new wavelength standards around 193 nm for the ArF excimer laser. Previously the group obtained precise new laboratory data for lines emitted by the F_2 laser near 157 nm, while another group in the division provided improved index-of-refraction data for CaF_2 and BaF_2, of great importance to optical designers of lithographic instruments using the 157-nm source. In a major effort to "stretch" this technology, the industry is now focused on light sources at EUV wavelengths near 13.4 nm. The spectra of highly charged ions of xenon are of major interest for this new technology. The Atomic Spectroscopy Group has now obtained new laboratory observations of these spectra at wavelengths below 14 nm. At the same time, the group is moving rapidly to compile and disseminate a comprehensive database for as many Xe ions as possible, in support of the EUV lithography initiative. Finally, Intel and SEMATECH have provided significant funding for the Plasma Radiation Group to use the EBIT to explore the properties of thin-film and multilayer structures needed in the development of EUV lithography light sources. The laboratory's expertise in x-ray optical systems is being tapped to support the U.S. fusion program by designing a diagnostic module for the NRL to be delivered to the NIF.

It appears that closer ties to industry are being developed with respect to the precision optical metrology work, and additional ties should be encouraged. Connections should continue to be made with academia and industry for the biological-related X-ray activities to ensure that the proposed work is relevant to the needs of this community. If adequate staffing were available, collaborations should be sought between NIST and the third-generation X-ray synchrotron sources at which issues similar to those being addressed at NIST (high-precision angle measurement, comparison of surface roughness measurements using visible light, X-rays, and atomic force microscopy, and so on) are also being pursued. However, given the current manpower situation, it is clear that this simply cannot occur.

Division Resources

The eroding base support for the scientific programs of the Atomic Physics Division has been offset by extensive use of contractors and visitors. However, the panel is concerned for the long-term financial health of the division.

In discussions with a small sample of division contractors, it became clear that a number of issues need to be addressed. In particular, while the contractors were excited about their work and felt that they are treated very well by the NIST scientists with whom they work, they also felt that their compensation was inadequate to allow for a moderate standard of living in the area near NIST. In addition, obtaining adequate health care insurance is apparently a problem for these people. Many of the contractors are foreigners and are currently experiencing substantial difficulties with visas. Given the widespread use of contractors by NIST, it is important that the division and the laboratory aggressively pursue means to improve their situations. These issues are likely not specific to the Atomic Physics Division or the Physics Laboratory, but the panel mentions them here as an observation from staff-level discussions.

The division is anticipating a long-awaited upgrade in facilities with the upcoming opening of the new Advanced Measurement Laboratory. There was concern expressed to the panel that these new facilities may be accompanied by a substantial overhead tax that would adversely affect base funding.

At the time of last year's review, the Quantum Metrology Group was already at a subcritical staffing level, with just four permanent staff. Presumably because of their expertise and experience, two of those staff members were recruited to work on pressing national security problems during the past year. This situation has recently been exacerbated with the retirement of the group leader, effectively leaving 2.5 full-time equivalents (FTEs) working in the focus areas of the group, with the remaining 0.5 FTE continuing to work on homeland security. Although the remaining members of the group are early in their careers and very enthusiastic about the work they are performing, additional staff is critically needed to keep the group viable. To retain the expertise of this group a more aggressive hiring plan should be developed, embracing not only permanent staff but also postdoctoral associates and/or visiting scientists, or using other creative approaches to increasing staff numbers.

A continuing concern over the past several years has been the long-term viability of the Atomic Spectroscopy Group, given its aging staff and inadequate funding. In last year's report the panel expressed serious concerns on this subject. It is gratifying to note that, as of this year's review, the prognosis for the group appears much improved. The Atomic Spectroscopy staff now includes several young members who can be easily viewed as forming the future core of the group. The energy and passion of these younger scientists are evident and contribute to the optimism of the group as a whole. The Physics Laboratory has provided a basic level of funding for the group, which has had a successful year in attracting new grant funding from various sources. Although the group is not growing dramatically, at least its situation has stabilized, and its outlook for the future is brighter.

A matter of concern to the panel is that one or two of the promising new, younger staff members are emigrants from Russia. Their ability to join the staff for the long term depends on their ability to establish the appropriate immigration status in this country. Also, the continuing rise of overhead costs will make it financially difficult to add these individuals to the core staff unless the cost is offset by the retirement of older staff members. It is hoped that some financial flexibility will allow these transitions to be smooth and rational.

Another matter of concern to the panel is that much of the division's equipment is very old. To keep up with future demands for precise atomic spectroscopic data and to attract new "business" will require steady modernization of equipment and facilities over a period of years.

OPTICAL TECHNOLOGY DIVISION

Technical Merit

The Optical Technology Division advances knowledge, develops expertise, provides technical leadership, and delivers the highest-quality standards, calibrations, and measurements in targeted areas of optical technology. Optics and optical technology are broadly construed to include the spectral range from the microwave region to the vacuum ultraviolet. The division is currently organized in four groups: Optical Thermometry and Spectral Methods, Optical Properties and Infrared Technology, Optical Sensor, and Laser Applications. This organization is largely administrative in nature, as productive interaction among individuals, groups, and other NIST laboratories is an avowed goal of division management.

Within NIST, the Optical Technology Division has the institutional responsibility for maintaining two base SI units: the unit of temperature above 1234.96 K and the unit of luminous intensity, the candela. The division also maintains the national scales for other optical radiation measurements and ensures their relationship to the SI units.

The division maintains a long-term, core commitment to high-accuracy measurements in radiometry, photometry, and spectroradiometry. It has invested significant resources in these areas and justifiably places emphasis on maintaining the laboratory investments and carefully derived measurement methodologies as tools for external customers in the private and government sectors. The panel commends the division for its continuing efforts to develop new approaches to calibration over a wide spectral range, from the far-IR through the EUV, and to seek new means of meeting customers' needs through transportable calibration techniques and technologies. New developments that enable measurements with greater customer convenience include the Facility for Automatic Spectroradiometric Calibrations, FASCAL-II, a detector-based spectral irradiance calibration capability that has recently been brought online to complement the earlier version of this instrument, and the transportable Missile Defense Agency (MDA) transfer radiometer. Also addressing these needs are the SIRCUS and "traveling SIRCUS" systems that use tunable laser technologies. The UV-VIS SIRCUS is now fully operational and is proving to be extremely useful for the calibration of various radiometers for both irradiance and radiance spectral responsivity. More than 9 decades of dynamic range have been achieved, and the spectral bandwidth is minuscule in comparison with measurements using dispersive instruments. The IR-SIRCUS is also nearing completion. These facilities support remote site work for NASA, the National Oceanic and Atmospheric Administration (NOAA), the MDA, and other DOD agencies. Also, the Thermal IR Transfer Radiometer facility will support various NOAA/NPOESS (National Polar-orbiting Operational Environmental Satellite) and DOD needs over the next decade and beyond. The current development of the High Accuracy Cryogenic Radiometer (HACR-2), with higher sensitivity, greater dynamic range, and more operational flexibility than the current HACR system is another good example of the use of in-house expertise to better meet future customer requirements.

A unique facility available at NIST is the SURF III synchrotron source. It offers a distinctive and important approach to absolute radiometry. New beam lines have enhanced the capabilities to characterize detectors and components in the UV, VUV, and EUV. Transfer standards at all of these shorter wavelengths are becoming increasingly important to the semiconductor industry. The UV regime is now very critical in the semiconductor industry for lithography and metrology purposes. The panel feels that the analytical and metrology platforms created for predicting and measuring the optical properties of materials such as CaF_2 and other relevant UV materials used in the semiconductor industries could now be usefully expanded.

Many of the classical materials have been improved or "cleaned up" dramatically relative to their state decades ago. In addition, many of the traditional optical properties need to be remeasured at shorter wavelengths and/or to greater accuracy and in some cases, at higher fluxes. It would be appropriate to undertake a study to determine which materials would merit further characterization. Much of the ensuing work would benefit from the excellent theoretical and experimental foundation built by NIST researchers.

The Absolute Pyrometry project, which will ultimately result in the ability to maintain the SI scale of thermometry above a temperature of 1235 K, is progressing well. Several measurements have been made on a variety of blackbody optical radiation sources, demonstrating the feasibility of this approach. Plans have been made to extend to lower temperatures using InGaAs and InSb detectors to connect with ideal gas thermometry. Similar plans have also been made to realize an accurate scale at elevated temperature using high-band-gap detectors. This work supports the national responsibility for maintaining the SI scale of temperature.

Optical materials characterization is an important and vital part of the division's activities. A long tradition of expertise and instrumental capabilities is available for infrared studies. At present, the FTIR facility for materials characteristics and standardization continues to show good progress. Only a few steps remain before this instrument becomes fully operational. This is a unique facility that permits simultaneous infrared measurements of emittance and reflectance with multiple blackbody sources for wide wavelength coverage. It will be a valuable complement to the division's extensive infrared characterization capabilities.

The use of light-emitting diodes (LEDs) for lighting, signaling, and display applications is a growth industry, prompted by the continued advances in LED spectral coverage, versatility, and efficiency. The Optical Technology Division has recognized the expanding needs for LED characterization and associated photometric standards and has evolved its tools and adapted its resources to meet these needs. The capabilities now exist to measure intensity, flux, angular distribution, and spectral properties of LED devices as a function of their operating conditions (drive current and temperature). Packaged temperature-controlled LEDs are being characterized and may make useful standards. New colorimetric facilities are employed for their spectral characterization, and they may also be applicable for colorimetry of new LCD display devices. The NIST calibration services for color-measuring instruments used by the private sector lighting and display industry will be well used in future years.

Another recent initiative concerns the instrumentation to characterize retroreflective materials and the development of corresponding standards. The radiometry/source end is nearly complete, and the sample goniometer is in the design phase. The panel believes that this is an important project that has diverse types of potential impact, notably in the area of highway safety.

The Optical Technology Division is active in providing unique new spectroscopic tools and applications in selected areas. Currently, one of these focus areas is the exploration of the terahertz or far-infrared spectral region. This part of the electromagnetic spectrum is of great scientific and technological importance but has traditionally been a difficult one to access because of the lack of tunable coherent sources. In a laboratory-wide Competence program, new sources, techniques, and spectroscopic applications are being developed. The division continues to be a leader in these areas. Both continuous-wave and time-domain spectroscopic techniques are being developed and refined. The CW techniques are based on specialized electron devices, as well as on the extension of traditional approaches using FTIR methods. The time-domain methods utilize the division's extensive expertise in femtosecond lasers and nonlinear optics to generate and detect single-cycle pulses of far-infrared, terahertz (THz) radiation. These new capabilities are being used for measurements that include studies of biological molecules and their building blocks—research that is resulting in numerous publications. Applications to biotechnology and national security are clear. For example, although the absorption spectra of proteins and their building blocks are exceedingly complex, the identification of resonance structures that can be distinguished from those of sugars and cellulose provides the potential for spectral discrimination techniques. The laboratory resources for this work are well organized and well maintained. Taken in totality, the division's terahertz radiation program is one of the most extensive and advanced in the world.

Small structures represent another major frontier in optical spectroscopy, with significant impact in priority areas from semiconductor technology to biotechnology, as well as great inherent scientific interest. In response to needs in this area, unique capabilities have been and are currently being developed to probe thin films, surface layers, organic and inorganic nanostructures, and even single molecules. These activities are well aligned with other major initiatives in NIST and with areas of external importance, such as bio- and nanotechnology, photonics, and electronics. With respect to precision measurements of surfaces and interfaces, the broadband, infrared-visible sum-frequency generation spectroscopy pioneered in the Optical Technology Division provides the power of an interface-specific optical technique with the possibility for rapid data collection of vibrational spectra. The division team has demonstrated the utility and uniqueness of this approach in several noteworthy studies. These contributions have had a marked impact on laboratories throughout the world. In ongoing investigation, recent advances have included the use of doubly resonant (vibrational and electronic) excitation to enhance the sensitivity and selectivity of the method. This has been successfully demonstrated in studies of the chemical groups in DNA monolayers.

In complementary work, the division has successfully initiated the development of new, optical scattering metrology techniques and associated models that have a broad range of applications in studies of surface structures, film or layer properties, and particle deposition on surfaces. This research is an outgrowth of the division's established expertise in the precise analysis of optical scattering. Recent developments have direct relevance to the semiconductor industry. The associated development of a public-access library of software tools for customers to use in their own particular applications areas has been very successful. It is difficult to quantify the impact that this type of service has on the larger community, but the fact that the software library Web site has experienced more than 1,000 downloads in the past year is a good indicator. The laboratory facilities for this initiative are currently constrained and could certainly benefit from the commitment of more space, particularly in a low-vibration environment. Plans for expansion should be realized in 18 to 24 months when a new building becomes available for occupancy. There may be significant added benefit of this work to the semiconductor industry by extending the instrumentation into the UV.

The ultimate limit of spectroscopy for small structures addresses the detection of single molecules. To meet this challenge, the division has a leading-edge program to develop the necessary tools and techniques for such measurements and to pursue significant applications to problems of biological significance. These measurements rely on the division's expertise in confocal and near-field microscopy and fluorescence detection of weak signals. This knowledge has permitted researchers in the division to perform impressive experiments on the measurement of distances on the nanometer scale by means of an adaptation of the technique of fluorescence resonant energy transfer. These investigations have the potential for significant impact in biophysics and biotechnology. A key ingredient in the success of this program is the very strong integration of these and other efforts in the division with unique resources available from the nearby NIH facilities. The panel was struck by the very close collaborations that had been established and by the mutual benefits to both sides resulting from these interactions.

Program Relevance and Effectiveness

Given the breadth of the programs within the Optical Technology Division, their relevance and effectiveness should be gauged by several different measures, ranging from their purely scientific impact, through the publication of high-impact papers and major invited talks, to the direct fulfillment of customer requirements for calibrations and standard reference materials. The panel's overall assessment is that the division's activities, each evaluated by the appropriate metric, are highly relevant and effective. This relevance and effectiveness reflect in the first instance the excellent caliber of the division's staff, their ability to form useful collaborations within NIST and with relevant external organizations, and the division's consistent and thoughtful management. In addition, however, the division's effectiveness is gauged by its responsiveness to the outside world. The panel believes that the division has done an admirable job both in terms of identifying and fulfilling customer needs and in terms of continually realigning the research agenda to stay at the technical forefront, while pursuing problems optimally matched to NIST's resources and mission. A sign of this vitality can be found in the significant shift of research activities that has taken place over the past years and which continues to take place at the present time.

The importance of the division's continued interactions with colleagues and customers from other government agencies, industry, and academia is obvious. The level of funding support from these customers, and from the ATP program, represents a very significant fraction of the total revenue base and is vital to the future of the division. The fact that the division has such strong interactions with partners external to NIST is testimony to its relevance and reputation. In addition to the inherent quality of the work and the instrumental resources available, in several areas the panel noted the effectiveness of nonregular employees, such as postdoctoral research associates and visitors. Beyond their ability simply to expand the workforce in a flexible fashion, these individuals are a constantly changing source of new perspectives and serve as a bridge to critical outside and international groups. The panel also recognizes, however, how thinly division resources are being stretched. In many areas the departure of a *single* regular staff member could significantly affect major programs.

Relevance to the external community is exemplified in a number of areas of emphasis. In addition to the traditional in-house calibration capability, the division has been responsive to critical needs for transportability. This responsiveness has led to the development of new instrumentation and the capability to place key personnel and measurement systems at customer sites. The BXR, TXR, and Traveling SIRCUS programs mentioned above are good examples of this approach. NASA, the Missile Defense Agency, and other DOD agencies expend significant resources on field studies and for on-site calibration and validation activities for which transportability is vital.

The short courses offered by the division are clearly also of great value to the external technical community, filling a distinctive need. The division has recently added to its listing of short-course topics. These give the participants an opportunity to use state-of-the-art laboratory equipment and measurement techniques and to interact with experts in the field. Complementary online tutorials and library offerings, such as those of SCATMECH (a consortium of 14 U.S semiconductor manufacturers), have recently added to the tools that can be employed to use the in-house expertise to support the customer. Continued development of online courses would be effective in reaching a wider audience. The division should be encouraged to highlight these educational, technology-transfer activities to a greater degree in its strategic plan and in its brochures.

Within the Optical Technology Division there is also an emphasis on responsiveness to national security needs. NIST envisions a significant role in supporting homeland security, and the division has responded in a timely and well-considered manner. The division's widely recognized expertise in fundamental and applied spectroscopy has been utilized in the recent efforts to investigate the viability of spectroscopic detection of biological hazards in sealed paper envelopes. In this case, investigators have found promise in the use of new spectroscopic detection techniques at terahertz (far-infrared) frequencies. This effort also demonstrated an effective collaboration with and support of other government agencies to address critical national defense needs.

The high level of cross-group interaction that is evident in many areas in the division is commendable. The division has recently reorganized into four groups, eliminating two of the older groups in an attempt to use existing resources more effectively. Such reorganization is to be expected, given the NIST budget trends and the increasing relative importance of the division's responsiveness to pressing needs of external customers. The significant number of small teams that consist of members of multiple groups not only reduces the stress associated with reorganizations, but also enhances the division's capability to implement its strategic plan.

It is a natural consequence of the diversity of the scope of technical work in the division that planning is accomplished through a variety of approaches, including individual interactions with customers, specific industries, and collaborating researchers. Complementing these approaches in a significant fashion, however, is the active involvement of the Optical Technology Division in consortia. These activities are vital to communicating the division's expertise to the outside world and, conversely, for taking the views of the outside technical community into account in formulating the division's research agenda. In this respect, a special role is played by the Council for Optical Radiation Measurements (CORM), which evaluates national needs in optical metrology and provides feedback on the services and standards supplied by the division. CORM, a body originally instituted by NIST to provide guidance and prioritization on technical needs in industry and research, is clearly a well-functioning entity. The colorimetry facility, for example, was developed in response to CORM recommendations. The panel believes that communication between CORM and NIST could be more effective if the timing of responses were optimized. As a procedural matter, the poll of CORM members currently occurs prior to the issuance of the NIST response to the previous report, and the CORM report essentially coincides with the NIST response. A mutual agreement should be sought between NIST and CORM whereby NIST produces its response in a fixed time (say, 2 or 3 years) after the issuance of the CORM report. Up to 1 year should be allowed for assessment of the response. The polling for the next CORM report may then be initiated. The division has also maintained a dialogue with the UV Measurements Focus Group of the industrial association RadTech International North America.

Division Resources

Despite the ambitious technical objectives of the Optical Technology Division, its budget is tightly constrained, and the number of permanent employees is strictly limited. To meet the goals of the division, extensive use is being made of personnel in various other budgetary categories, such as postdoctoral research associates, contract employees, and emeritus staff. The presence of scientists in these nonregular job categories significantly extends the capabilities of the division. At the same time, it provides for the needed flexibility to accommodate changes in funding levels and program emphasis. This mode of operation appears to the panel to be effective, although care must be taken to avoid losing critical expertise within the permanent staff, which could have a significant impact.

The key resource for the division is, of course, its technical workforce. In its discussions, the panel found, in accordance with recent laboratory-wide surveys, that the level of morale was high. Other than concern about the tight budgets and significant budgetary uncertainties associated with the outlook for the ATP and other programs, the panel did not identify major personnel issues.

The Optical Technology Division is home to several unique pieces of instrumentation that underlie the mission of the division. Facilities maintained and developed by the division include the SIRCUS, HACR, SURF, and instrumentation for the determination of the temperature scale in the high-temperature range. The division has continued to devote resources not only to the maintenance of existing facilities but also to their upgrade, with respect to both technical specifications and ease of operations. This trend is illustrated by the shift toward source-based rather than detector-based radiometry, the former being more convenient for the generation of transfer standards and the ready calibration of commercial instrumentation.

IONIZING RADIATION DIVISION

Technical Merit

The Ionizing Radiation Division's mission is to provide national leadership in promoting accurate, meaningful, and comparable measurements of ionizing radiations (X-rays, gamma rays, electrons, neutrons, energetic charged particles, and radioactivity). The division is composed of three groups: Radiation Interactions and Dosimetry, Neutron Interactions and Dosimetry, and Radioactivity. The Radiation Interactions and Dosimetry Group focuses primarily on medical and industrial radiation processing and on radiation-protective applications, and it engages in computational studies and the development of codes. The activities within the Neutron Interactions and Dosimetry Group are related more to fundamental work, nuclear power, and neutron standards and cross sections, although this group supports radiation protection applications as well. Efforts within the Radioactivity Group center on medical, environmental, and radiation-protective applications.

During this review the panel concluded that the division continues to accomplish outstanding scientific and technical work and to provide strong support to the broader scientific and commercial communities. Results of its work are shared through technical publications and presentations, involvement in national and international standards organizations, and leadership and participation in workshops of relevant topical areas. Discussions of accomplishments and their technical merit are provided in the following subsections, by group.

Radiation Interactions and Dosimetry

This Radiation Interactions and Dosimetry Group is concerned with four areas of scientific and technical activity: (1) theoretical dosimetry, (2) industrial dosimetry, (3) medical dosimetry, and (4) protection and accident dosimetry. Additionally, the group's expertise has been a crucial element in support of the national homeland security initiative.

Theoretical programs of the group continue to make significant contributions in both the national and international communities. The Photon and Charged-Particle Data Center compiles, evaluates, and disseminates data on the interaction of ionizing radiation with matter. The quality of the work of the data center is reflected in the many requests for information that it receives from other laboratories and in the appearance of these data in engineering and scientific compendiums, in books and review articles, and in the reports and protocols of national and international standards organizations. A new evaluation of cross sections for the elastic scattering of electrons and positrons by neutral atoms has been completed. This work has contributed greatly to the efforts of a committee reporting on the elastic scattering of electrons and positrons, sponsored by the International Commission on Radiation Units and Measurements (ICRU). The Theoretical Dosimetry team has used Monte Carlo calculations to determine new wall corrections for the NIST chambers, for photon energies pertinent to NIST standards for ^{60}Co, ^{137}Cs, and ^{192}Ir gamma-ray fields. These results will be used to revise NIST standards as part of an international effort to harmonize standards using the best wall corrections.

Industrial dosimetry projects continued in a number of other areas, including homeland security. After last year's successful demonstration of the test version of the new Internet-based calibration services for the radiation processing industry service, efforts began on the next-generation system. A detailed operations scheme for this new service has been developed, and work to build it has started through a contract with Advanced Technology Research Corporation, although the project has been slowed by a lack of resources. In support of this online calibration service, a new film dosimeter has been tested and found to improve the quality of industrial processing using ionizing radiation. This Internet-based service will be an important asset to the industrial irradiation community and could prove to be a significant source of revenue for the division. The panel strongly recommends that resources be found to complete this project.

In the area of tooth-enamel biodosimetry, a final report has been issued to the National Cancer Institute summarizing the reconstructed doses for 72 teeth collected from the population of eight villages located in the vicinity of the Semipalatinsk nuclear test site in Russia. This unique project has established a new technique that can be used by epidemiologists interested in the effects on populations of prolonged exposure to low-level radiation. In addition, the group continues to provide a measurement assurance program and consulting services for the Navy's high-energy X-ray facilities (420 kilovolts peak [kVp] to 15 MeV). Development continues on beam-line and imaging components for a high-energy X-ray computed-tomography system on the NIST Medical-Industrial Radiation Facility (MIRF) 7- to 32-MeV electron linear accelerator. This system will be used in the development of techniques and systems for industrial imaging, including the creation of a testbed facility for cargo container inspection. The MIRF tomography facility will be unique in that it will be able to perform measurements at X-ray energies significantly higher than are currently available at other facilities. Further, a significant flux of neutrons from the X-ray converter may be useful for simultaneous neutron interrogation of the contents of containers.

Several important areas of research and development supporting advanced medical treatments are being addressed in the Medical Dosimetry team. This work will provide external and impartial quality assurance for the safety of patients as treatments become more complex and more opaque to the providers. Although there are regional centers that provide routine services, NIST remains the sole cornerstone for this important area of research, standards, and calibrations, and it should be well supported.

Increasingly sophisticated means of delivering external radiation beams for therapy has resulted in complex, computer-controlled accelerators, delivery systems, and control systems that frequently cannot be accessed or monitored directly by the operators or the physicians. Intensity-modulated radiotherapy, dynamic conformal therapy, and tomotherapy represent examples of such technologies that are in the clinic or in development. It is essential that NIST lead in the development of standards for such procedures, and the new acquisition of a clinical linear accelerator is to be lauded. It is imperative that the system be brought online quickly and that a long-term plan be developed for its use and for the role NIST will play in such modalities.

In the area of protection and accident dosimetry, a number of projects of interest have been completed or are ongoing. 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 standardized techniques developed for this process at NIST and the Physikalisch-Technische Bundesanstalt are now activities included in an ISO draft standard, and they are being implemented in the NIST calibration service. The design and assembly of a new calibration range for low-level ^{137}Cs have been completed and will be used for the calibration of ionization chambers and other photon detectors at very low air-kerma rates. An investigation has also been initiated to demonstrate the magnitude of the change in the response of thin-walled ionization chambers due to varying wall thickness when used in ^{137}Cs and ^{60}Co radiation fields. These unique and state-of-the-art facilities again demonstrate the quality and technical merit of the Ionizing Radiation Division's programs.

In the area of homeland security, two divisional groups played major technical roles in the homeland security area in 2002, while the division chief led a task force established by the White House Office of Science and Technology Policy. The Industrial Dosimetry and the Theoretical Dosimetry project teams worked with the Armed Forces Radiobiology Research Institute, the United States Postal Service (USPS), and industrial irradiation facilities to provide critical dosimetry measurements for the validation of electron irradiation of mail to kill anthrax spores. In addition, the division cooperated with other parts of the NIST Physics Laboratory in areas such as the dosimetry of spore-kill validation experiments for the different electron beam parameters at the two industrial irradiation facilities used to treat contaminated USPS mail, and in the quantitative analysis of volatile organic chemicals and other potential irritants produced in mail packages during irradiation processing. Further, collaboration between the Ionizing Radiation Division and the Chemical Science and Technology Laboratory's Biotechnology Division produced encouraging data regarding the applicability of existing DNA profiling tests to mail treated with high doses of ionizing radiation. In essence, they demonstrated that irradiation did not affect DNA to any significant degree, and it could therefore still be used for forensic purposes. Similarly, the Radiation Interactions and Dosimetry Group participated in a collaborative investigation on the effects of high doses of radiation on archival documents.

The division continues in collaborative efforts to improve the processing of mail. Based on an extensive program of Monte Carlo radiation-transport calculations, the Theoretical Dosimetry team provided advice on the optimization of the processing-system parameters and the strategies to effectively handle the highly variable mail and parcel stream. The effectiveness of the projects supporting homeland security, and the speed with which they were initiated and in many cases completed in 2002, speak highly of the technical merit of the work done by the Radiation Interactions and Dosimetry Group.

Neutron Interactions and Dosimetry

The Neutron Interactions and Dosimetry Group continues its work at the forefront of research that contributes to the understanding of basic physical principles and contributes new methods for calibrations and standards used by industry and medicine and in support of national technical initiatives. The work focuses on four main areas: (1) fundamental neutron physics, (2) standard neutron fields and applications, (3) neutron cross-section standards, and, with increasing emphasis, (4) homeland security. The panel notes that the availability of such a group to respond rapidly to national crises and to support homeland security demonstrates the importance of preserving our intellectual and technological resources in the areas of radiation physics and dosimetry, particularly in the area of neutron dosimetry.

Work on the development of the ultracold neutron source, a unique facility at the NIST Center for Neutron Research being used for basic research with other institutions (at 11 different states and 7 other countries), has continued to make notable progress. A second monochromatic beam of very long wavelength neutrons (~0.9 nm) has been added, and a new mezzanine was added above the 0.5-nm beam line to provide much-needed additional research space. Experiments are in progress on all three beam lines, with the new 0.9-nm line resulting in better neutron lifetime measurements. In collaboration with Harvard University, neutron-trapping studies operating on the new beam line began this past year. An improved experiment is under way in an attempt to detect a time-reversal asymmetry term in neutron beta decay. Research into the neutron lifetime and decay asymmetry could test the applicability of the Standard Model of particle physics, improve our knowledge of the nuclear weak couplings, and test the Cabibbo–Kobayashi–Maskawa matrix for three generations of quarks, experiments that are thought to be feasible only on the most energetic, most advanced, and more costly accelerator facilities. The assembly of the polarized beam line was completed this past year.

With these improvements, including an improved detector that is collecting data at about 10 times the previous rate, the group—in collaboration with the lead institution, the University of Washington—can already improve on the previous limit obtained in 1997 for the limit time-reversal asymmetry term. This now allows the development of neutron spin filters for work in materials science and fundamental physics. The group has begun tests to establish the viability of using polarized ^{3}He spin filters for diffuse reflectometry. In collaboration with the Massachusetts Institute of Technology, the neutron interferometry system is being used to study phase de-coherence in quantum information processes, with the potential for major impact in this field in which NIST now has an international reputation.

The NIST subgroup for Standard Neutron Fields has a new facility for neutron radiography and tomography installed on the BT-6 port in the Center for Neutron Research's confinement building for outside users. Care has been taken in the arrangements to support proprietary use by industrial users. This new imaging modality has broad application in the development of alternate energy sources, environmental applications, and homeland security. It already has been used to quantify chemical processes in sealed fuel cells nondestructively and in situ—imagine that cannot be done any other way. This group has also has been working with the national standards laboratories of the United Kingdom (the National Physical Laboratory [NPL] and Germany (Physikalisch-Technische Bundesanstalt [PTB]) for an international (blind) comparison of neutron fluence rate measurements. The NIST results were reported during this past year and are in agreement with the NPL results, but there is a difference with PTB of about twice the uncertainty estimated by NIST, again showing the value of vigilance in the area of standards and calibrations.

Radioactivity

The Radioactivity Group continues to be involved in four principal areas of scientific and technical activities: (1) standards and methods, (2) metrology in nuclear medicine, (3) metrology and monitoring related to the environment, and (4) quality assurance and traceability programs. The group is largely responsible for establishing and maintaining the primary standards for radioactive counting provided by NIST as a service to the technical and scientific community. The Radioactivity Group focuses on preparing radioactive standards SRMs, developing calibration methods, and providing NIST-traceability to customers in fields ranging from nuclear medicine and radiopharmaceuticals to environmental monitoring and nuclear power. As a result, its primary efforts continue to be very customer-oriented, although the Radioactivity Group also engages in basic and applied research. Its research efforts center on developing the requisite methods and measurement technologies for ensuring that it remains at the cutting edge of measurement science and can meet the varied needs of its user community. Of particular note in the Radioactivity Group is a new initiative in the area of homeland security.

The work of the Radioactivity Group in the area of standards and methods serves critical needs for the development and standard use of radioactive devices in industry, medicine, defense, and academia. Activities associated with metrology in nuclear medicine include providing measurement and calibration support for the development of standards as well as for new and existing radioimmunotherapy agents and devices. Of special note this year is the addition of microcalorimetry to the mix of techniques used for calibrating brachytherapy sources. For the case of long-lived radionuclides such as ^{90}Sr, uncertainty limits were found to be wholly dependent on the reproducibility of the calorimeter's power baseline. By using multiple insertions of the sample and meticulous attention to detail, the experimenter was able to overcome any problems with baseline variations. In fact, this work marks the first calorimetry-based radionuclide standardizations work to be performed at NIST in more than 35 years, despite the fact that calorimetry is usually considered the most direct and least perturbed method of measuring the dose.

In addition to completing the standardization of ^{90}Sr–^{90}Y brachytherapy seeds, calorimetry was used for the primary standardization of ^{103}Pd seeds used to treat prostate cancer. The latter work comprised a very intricate set of experiments involving ion chamber measurements, calorimetry, destructive radiochemical analysis, liquid scintillation counting with efficiency tracing and using the Triple Double Coincidence Ratio technique (see below), and finally, photon emission spectrometry. This work established some restrictions in the composition of sources that can be used for calorimetry owing to potential radiation chemistry effects.

Other notable efforts in the nuclear medicine metrology area include a continuing set of meticulous experiments to determine the effect of factors such as solution pH and ionic strength and the presence of chelators, as well as the choice of commercial scintillants, on the accuracy of assays by the liquid scintillation technique. In addition, considerable progress has been made on the development of the Triple Double Coincidence Ratio system that will obviate the need for tritium efficiency tracing. The Triple Double Coincidence Ratio, which was initially developed and demonstrated at NIST's "sister" laboratory in France, has now been successfully implemented within the Radioactivity Group at NIST. The other notable effort in this area concerns addressing the needs for standards and measurement quality assurance programs for Food and Drug Administration (FDA)-approved radiopharmaceuticals as they come on the market. NIST is now engaged in developing protocols by which dose calibrators can be calibrated directly at the clinical sites for newly approved radiopharmaceutical agents.

Metrology efforts associated with personnel and environmental monitoring require the ability to measure radionuclides at very low levels; as a result, much of the work in this area involves careful sample handling and preparation under highly controlled conditions in a clean-room facility. Of particular note in this area are the ongoing efforts associated with the 2nd Intercomparison Study for Detecting μBq Quantities of ^{239}Pu in Urine by Atom Counting. This work, which directly supports the DOE program to resettle the Marshall Islands, is comparing four different atom-counting techniques—inductively-coupled plasma mass spectrometry, fission track analysis, accelerator mass spectrometry, and thermal ionization mass spectrometry—to determine the best technique(s) for quantifying plutonium (Pu) at or below the 20 μBq/L level. This effort has obvious applications and will provide a needed exercise and evaluation of the laboratories involved in assays related not only to occupational health programs but to nuclear nonproliferation and counterterrorism as well.

The major new thrust for the Radioactivity Group for 2002 involved support of homeland security. To this end, test facilities for the calibration and testing of portal monitors, handheld detectors, pagers, and isotope identifiers are being established and used to test and compare the efficiency, precision, and accuracy of 10 commercially available instruments. Complementing these efforts are activities designed to define and develop a new set of Standard Reference Materials to be used as check sources for different types of detectors used for homeland security applications. In addition, a cargo container test facility for detection of low-level radioactive sources in transit has been established. The test facilities represent an ongoing effort to provide a system that will allow testing of the performance and limitations of a broad variety of detectors used to detect radioactive materials in transport.

In an ongoing effort to maintain NIST work as the state of the art in measurement science, the Radioactivity Group engages in basic and applied research to develop new or to improve existing capabilities. At the present time, the Radioactivity Group has activities in the following areas: resonance ionization mass spectrometry (RIMS), thermal ionization mass spectrometry (TIMS), large-source radiation imaging using a storage photo-stimulable phosphor imaging plate detection system, gamma-ray spectrometry, and radiometric calorimetry.

NIST is investigating the use of RIMS using glow discharge atomization and continuous-wave laser excitation to measure long-lived, low-energy beta- and X-ray-emitting radionuclides that are not easily measured using conventional radiometric techniques. Because this technique holds the potential for both high selectivity and high efficiency, RIMS is expected to significantly reduce the time required for the determination of absolute activity by completely bypassing the need for lengthy radiochemical separation procedures. Further, RIMS is independent of the properties of nuclear decay and offers the advantage of being able to measure several isotopes simultaneously. Consequently, maintaining a viable and robust RIMS capability would reduce costs to customers for these types of analyses. To date, RIMS has been evaluated for measuring $^{135}Cs/^{137}Cs$ isotopic ratios. Spectroscopic measurements confirmed existing values and demonstrated that it is possible to perform such measurements on subpicogram samples. Future plans include evaluating RIMS for the detection and measurement of Pu isotopes and atom trapping to achieve single-atom detection.

Program Relevance and Effectiveness

The program directions established within the Ionizing Radiation Division are both highly relevant to national needs and supportive of international cooperative programs. In many cases NIST is a unique resource, since it represents the sole impartial national agency for setting standards and calibrations for devices used in medical diagnostics and treatments and in the detection and monitoring of contaminants for individual and national security purposes. The strong theoretical knowledge base of radiation interactions with matter that has been developed at NIST over many years fosters new developments in the understanding of basic physical processes and underpins the standards and calibrations developments. The panel notes that during this review period the division continued to maintain a proper balance between its fundamental research and applied work to support the NIST mission and to enable advancements in several technological areas and rapid responses to national needs.

In the area of homeland security, the division promptly provided leadership and vitally needed dosimetry expertise and theoretical input for the safe and effective irradiation of mail to destroy anthrax spores. The group is continuing to play an important role in homeland security through the development of improved standards for the calibration of low-level radiation detectors (for use by first-responders in the event of a release of radioactive material and for X-ray surveillance equipment) and through the development of the High Energy Computed-Tomography Facility using the MIRF (for the investigation of the use of high-energy X-rays to interrogate, for example, cargo containers).

For the medical community, standards and calibrations were provided, both directly and through accredited secondary laboratories, for mammography and other diagnostic X-ray equipment, medical accelerators, isotope irradiators, and brachytherapy procedures for therapy, directly supporting the safe application, effectiveness, and increased use of these and other radiation-based treatments. In many cases, the calibration capabilities developed by the Radiation Interactions and Dosimetry Group are the only such facilities in existence. The customer base for these services is very large, including, for example, all U.S. facilities that perform mammography, as federal law requires yearly certification of the equipment.

The commercialization of the alanine dosimeter and development of the Internet-based calibration service that uses this device are important advances for the industrial irradiation community. Application of this technology directly supports the medical device industry and the fledgling irradiated-food-processing industry through the timely availability of NIST-traceable product dosimetry. Further, reliable NIST-traceable dosimetry might help to allay some fears currently associated with the radiation processing of food.

The Standard Reference Databases on interaction cross sections coupled with the Monte Carlo-based codes developed in the Physics Laboratory are a powerful tool that can be used quickly to assess potential new applications for radiation. The databases and codes available through the Ionizing Radiation Division are used extensively by standards, academic, and other organizations around the world. This capability is an asset that must be maintained and strengthened. In many medical and industrial applications, theoretical calculations represent the primary means of establishing the dose and dose distributions, with periodic experimental checks. Such is the case, for example, in the radiation treatments of patients.

The Neutron Interactions and Dosimetry Group is providing excellent fundamental research, with rapid translation to applications at NIST and in collaboration with other government agencies, medicine, and industry. Their work is resulting in new cross sections and calibration standards in fundamental physics at one end of the spectrum, while producing an international facility for neutron interferometry and optics at the other. Most recently, in the latter case, a new imaging technique has found immediate application in the commercial arena for calibrating chemical changes in sealed fuel cells. This new imaging modality can also have broad application in the development of alternate energy sources, environmental applications, and homeland security. The success of the Neutron Interactions and Dosimetry Group in melding an exceptional research effort with developments in standards and calibrations helps maintain the research caliber of its staff who, at the same time, recognize their important obligations to NIST's primary mission.

The Radioactivity Group has traditionally responded well to its customer base, and again this year the panel commends the new initiatives undertaken in support of emerging needs in the area of homeland security. The test facilities established for calibrating and assessing the performance of portal monitors, handheld detectors, pagers, and isotope identifiers should enable NIST to play a strong and increasing role in ensuring the reliability of this type of instrumentation to its user community. Similarly, the group's efforts to define and develop new Standard Reference Materials to be used as detector check sources in homeland security applications are an important and essential service. The panel also commends the group on its completion of a 4-year endeavor on the NIST Radiochemistry Intercomparison Program that provided measurement traceability for low-level environmental measurements in accordance with the acceptance criteria as defined in ANSI-N42.22, "Traceability of Radioactive Sources to NIST and Associated Instruments Quality Control." This work is now published. It is essential that the Radioactivity Group, as a service-oriented group, be abreast of the most suitable measurement techniques for determining isotope radioactivity. In this regard, through several years of concentrated effort, the Radioactivity Group is now ahead of the measurement community with its RIMS capability and has once again regained prominence in radiometric calorimetry for absolute radioactivity measurements.

Division Resources

In 2002, the Ionizing Radiation Division's budget increased by $1.3 million, from $7.7 million to $9.0 million, as a result of a one-time influx of funds to cover efforts related to homeland security, primarily those associated with the decontamination of mail. New funding for FY 2003 from contracts for work with others that are already in hand or expected soon includes funding for one project involving the irradiation of luggage and for another involving the use of neutrons to detect biological materials in sealed containers. At the present time, it appears that costs of much of the additional responsibility related to homeland security is being carried by the division's core operating budget. If additional funding for homeland security is not forthcoming in FY 2003, the division has developed contingency plans for making up the deficit. Budget prospects for FY 2004, however, look much brighter. The proposed FY 2004 budget shows an increase of about $5.3 million for NIST, much of which is expected to flow to the Ionizing Radiation Division.

As noted in past assessments, the division could benefit from having an adequate equipment repair and maintenance budget under the discretion of the division chief but independent from funds needed for standards and calibration activities and research. At the present time, funding for equipment repair and maintenance comes at the expense of not hiring additional staff and/or reducing the research effort, or equipment repair is delayed because the funds are used for hiring or research. In any case, this situation is problematic for a division whose core mission (e.g., standards and calibration) relies so heavily on instrumentation, detectors, and associated electronics, as well as on radioactive sources that have to be periodically replaced. A similar statement could be made for the need for an adequate budget for capital equipment. At the present time, only about $300,000 worth of capital equipment funds is available to the division per year.

With respect to equipment, the Ionizing Radiation Division has had an exceptional year. In 2002, it acquired a Varian Clinac 2100C medical accelerator from the Mayo Clinic. This machine, when installed and properly operational, will significantly expand its medical dosimetry program through the availability of therapy-quality electrons and photon beams. Further, during the year, two Titan Corporation SureBeam accelerators and a product-handling system were transferred to NIST from the USPS. The value of both the Clinac and SureBeam accelerators and handling equipment is estimated to be in excess of $4 million. Now that the division has this equipment, it is critical that appropriate space be dedicated and adequate funds be allocated for its installation and operation as soon as possible. To this end, space in Building 225 is available and is being readied for the Clinac. For the SureBeam equipment, the irradiation cell designated as A017 in Building 225 needs to be vacated by the optics group currently occupying this space. If this optics group is unable to move into the new Advanced Measurement Laboratory in a timely manner, installation of the SureBeam could be unduly delayed. Every effort should be made to ensure that this does not happen and that the estimated $750,000 for installation of the Clinac and SureBeam accelerators is made available when needed. In the neutron physics area, there is a growing need for improved neutron imaging capability both to support projects such as fuel cell imaging and for improved surveillance capability to support homeland security initiatives. To this end, there is a need for a larger, amorphous silicon flat-panel detector system. This larger detector would both improve resolution and allow larger areas to be imaged. Such a detector would cost approximately $150,000, and the panel believes that funds should be made available.

As of January 2003, staffing for the division included 36 full-time permanent staff members, of which 26 were technical professionals. There were also two nonpermanent or supplemental personnel, such as postdoctoral research associates and part-time workers. Because of increased efforts involving homeland security, three additional technical staff members were on loan half-time to the Ionizing Radiation Division from other organizations within the Physics Laboratory. Because of the budget uncertainties and rapidly expanding responsibilities during this period, hiring has appeared to center on replacing essential personnel who either took positions outside NIST or retired during the past year. Many of these replacements are employees hired on a nonpermanent basis.

As was mentioned earlier, with the exception of about 6 weeks during calendar year 2002, the burden of day-to-day management of the Radioactivity Group was the responsibility of the division chief. Although this situation was not ideal, it was manageable for 18 months while the group leader was on a rotational assignment to the Industrial Liaison Office within the NIST director's office. Next year similar managerial changes are on the horizon, with the division chief on leave for a year to the new Department of Homeland Security and the Radioactivity Group Leader serving as the acting division chief in his absence. This arrangement raises questions about continuity in leadership within the division. These changes and others that might result must be made carefully so as to preserve the strong management team and to keep the momentum and morale high among the staff.

All of the groups within the division feel the need to bring on additional staff. After a considerable downsizing of the division in the early to mid-1990s, the total number of division personnel has stabilized, remaining essentially constant over the past 5 years. However, during this same 5-year period, the responsibilities of division personnel and thus their workloads have changed in two important ways. First, the requirements for their core mission involving standards and calibration services have increased substantially. (Examples include the use of the neutron imaging facility for imaging chemical processes in fuel cells and the standards and calibration work associated with brachytherapy seeds, as well as standards and protocols for newly approved radiopharmaceutical agents.) Second, since September 11, 2001, the division has acquired new responsibilities, some funded and some unfunded, in support of homeland security. The increased workload, coupled with flat or declining budgets over the years, has put a strain on the existing workforce to the point that many staff members feel that there is little or no time for fundamental research or program development in traditional areas. In some cases, the research that *is* being done is carried out by necessity, and is focused on more applied metrology problems in support of the standards and calibration work. This research, although very applied, is in direct support of the expressed needs of the communities that the division serves, and its importance should be both recognized and supported by the Physics Laboratory and higher management.

In the Radiation Interactions and Dosimetry Group, at least two new hires are needed. First, a staff member is needed in the area of theory and modeling—a key hire in the effort to attain a critical mass with respect to supporting needed cross-section calculations and addressing new code development and other theoretical areas. Previously the staffing in this area had dropped to a single individual, who had both managerial responsibilities and full responsibility for the theoretical effort. Most recently a new staff scientist was added, but because this group remains the only such group in the nation committed to this area, an additional hire is warranted. The second key hire is for a person to champion the development of new standards, applications, and uses for the Clinac and SureBeam accelerators (see the preceding discussions of the equipment). Other needed hires for this group are two Ph.D.-level radiochemists, one to support the growing business associated with radiopharmaceuticals (particularly since the lead investigator is leaving for another multiyear position), and the other to take over the group's SRM program when the current leader of the program retires later this year.

The Neutron Interactions and Dosimetry Group has its own dedicated experimental beam lines and generally is well equipped to carry out its goals and responsibilities. It has a good balance of experienced senior researchers, but this group, along with others in the division, has remained constant in numbers of personnel while assuming new responsibilities such as those for homeland security. This group and others would benefit from a mechanism for providing a reliable and continuous source of postdoctoral fellows and junior research staff. In turn, such appointments would be a national resource of new scientists.

TIME AND FREQUENCY DIVISION

Technical Merit

The Time and Frequency Division supports U.S. industry and science through the following activities:

- Development and operation of standards of time and frequency and their coordination 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 meter on the realization of the second. This work contributes to a larger program in the Manufacturing Engineering Laboratory's Precision Engineering Division, which has primary responsibility for length and its dissemination. The division is organized in six technical groups, which are small in size but show very strong integration. These groups are Atomic Standards, Ion Storage, Time and Frequency Metrology, Network Synchronization, Optical Frequency Measurements, and Time and Frequency Services.

The overall impression of the panel is that the Time and Frequency Division remains technically strong, with a healthy balance of applied and basic programs. This division serves a unique and valuable purpose for scientific and technical communities in that it is the caretaker of the nation's primary standards for time and frequency measurements and possesses the knowledge and expertise to advance the precision and accuracy of these measurement capabilities. Details of current programs and their merit are discussed, by group, in the following subsections.

Atomic Standards

The Atomic Standards Group has made considerable progress in several areas that address the continuous refinement of time and frequency measurements based on atomic standards. The cesium fountain standard, NIST-F1, is established as the nation's primary standard. The frequency uncertainty of NIST's F1 is 1.2×10^{-15}. The division is focused now on improvement in the reliability and automation of NIST-F1, to provide more regular data. On the basis of the efforts of this group, NIST continues to define the state of the art in these measurements and is "tied for first place" with the Physikalisch-Technische Bundesanstalt in Germany for the performance of its primary frequency standards. Last year's clock comparison with PTB was the best ever, at 5×10^{-16}.

Design work continues on the second-generation NIST fountain, NIST-F2, which will load the atoms from a low-velocity intense atom source. NIST-F2 will use only one laser and will operate with a liquid-nitrogen-cooled drift space to control the uncertainty in the blackbody radiation frequency shift below 1×10^{-16}. The vision for NIST-F2 is to control the spin exchange frequency shift well enough to reduce its uncertainty to less than 1×10^{-16} by tossing multiple balls of atoms into the interrogation region. This uncertainty is needed to measure the gravitational shift in the Primary Atomic Reference Clock in Space (PARCS) experiment. Operations at liquid nitrogen temperature will also help control the frequency shifts induced by background gases. The overall accuracy goal for NIST-F2 will be 5×10^{-16}.

To support solid comparisons of primary frequency standards at the sub-10^{-15} level, improvements are being made in the stability of the NIST coordinated universal time (UTC) at the sub-10^{-15}-level timescale with respect to the UTC disseminated by the Comité International des Poids et Mésures. A complete replacement of the timescale hardware was due in January 2003; the existing equipment is more than 20 years old and has severe reliability issues. New electronics have already improved the signal-to-noise ratio substantially. Finally, new software is being written to appropriately weight the clocks in the ensemble and produce the output.

The continued improvement of time transfer is a key support element for primary clock comparison between international laboratories. Recently the U.S. Naval Observatory and NIST have undertaken a series of experiments to improve the performance of two-way time transfer. One comparison per hour has provided much-improved understanding of systematic and environmental effects. Tentative plans involve having a two-way satellite relay station installed at the Kauai, Hawaii, radio station site to better cover trans-Pacific Ocean two-way time transfer.

The two-way satellite time transfer equipment will have upgraded hardware this year; receiver up-converters with temperature sensitivity of <5 ps/°C will greatly reduce environmental effects. New GPS receivers are also being acquired. Two-way time transfer and the GPS carrier phase are comparable in performance, approaching 100-ps precision, which is the state of the art. The two techniques are both needed to provide a means of comparison: they mutually support one another's evolutionary improvement. The capability to do 200- to 300-ps time transfer with PTB last year enabled frequency comparisons at the 5×10^{-16} level with a 20-day averaging time. The current goal for two-way time transfer is 100 ps, which will likely need ionospheric corrections.

Ion Storage

The Ion Storage Group is devoted to the development of clocks based on mercury ions as well as to an effort in quantum logic. Two years' worth of data comparing the frequency of cesium to the mercury-ion is now available to project the constancy of these two measurements. With no control of systematics, the change in frequency of the mercury ion with respect to cesium is observed to be less than 1e-14. This surprisingly good performance suggests that even better results should be possible.

A key achievement of the past year is the definition of a universal logic gate, the so-called geometric phase gate. This gate appears to substantially ease requirements on lasers, for example, and is thus well suited to scaling the systems to larger numbers of ions, which in turn offers the potential for realizable, large-scale quantum computers.

Time and Frequency Metrology

Efforts of the Time and Frequency Metrology Group continue to develop phase- and amplitude-noise measurement capability and techniques for frequencies up to 100 GHz. This regime is far beyond the range of commercial instrumentation, and it has applications in high-speed digital devices, broadband telecommunications, and radar. The group's past work on the development of techniques for the measurement of phase noise of pulsed radar tubes is now in place in industry and working very well. The division's capabilities in this area are unique, both within the United States and internationally.

The group recently developed a clever means of adding a synthesizer to a reference oscillator in such a way that a single cavity can be used to clean up the noise. As a result, NIST will be able to handle measurements with larger dynamic range much more efficiently. Another highlight is the demonstration of a new measure of variance, which allows extension of averaging time to the length of the measurement interval. In contrast, the standard Allan variance provides data for only a fraction of the measurement interval. This new variance has obvious practical implications for characterizing long-term frequency stability in a shorter measurement interval, having a positive impact on the cost of frequency stability testing.

The group works on broadly tunable oscillators and participates in three Defense Advanced Research Projects Agency (DARPA) programs, which brings in approximately $1 million of external funding. With DARPA's new interest in narrowband microwave systems, funding is likely to increase further next year, so this group is likely to expand.

Network Synchronization

Currently the Network Synchronization Group is supporting standards projects primarily in the areas of time coordination and timescale upgrades. A collaboration between this group and the University of Colorado is aimed at improving the GPS carrier-phase method. Developments in this area will also be used for the PARCS space-clock mission. A highlight of recent work on the timescale is the development of improved steering of the timescale to UTC. This has reduced deviations of UTC(NIST) from UTC by a factor of two.

Optical Frequency Measurements

The Optical Frequency Measurements Group continues to develop and extend the applications of the optical frequency combs. These have been produced by injecting femtosecond pulses from a mode-locked laser into a microstructure fiber to broaden the spectrum to the required octave. A new mode-locked laser now directly produces an octave-spanning spectrum, which eliminates the need for the nonlinear fiber. This change increases the reliability of the system, which can now stay phase-locked for a day rather than a few hours. An optical frequency standard with a microwave output is obtained by locking a mode of the laser cavity to an atomic transition. This approach has the potential to achieve uncertainties 1,000 times better than those of the current best standards. To date, the electrical microwave signal generated by detecting the optical pulse train is somewhat noisier than the pulse train itself, but progress is being made on this issue.

Substantial progress can be reported on the extension of frequency-comb technology to 1.3- and 1.55-μm wavelengths in support of wavelength-division-multiplexing (WDM) systems to be constructed at these telecommunication wavelengths. A chromium-doped forsterite laser has been mode-locked and emits a 400-MHz pulse train at ~1.3 μm. These pulses will be frequency-doubled to obtain 657-nm light that will be locked to the corresponding transition of the Ca atom. Frequency combs could act as the basis for precision length measurement (at the 1×10^{-8} level), distributed by GPS.

The calcium optical frequency standard, based on a narrow resonance in calcium atoms that are laser-cooled and trapped in a magneto-optical trap, has very good short-term stability, limited primarily by the atomic velocity. Because its Q (the ratio of transition frequency to linewidth) is lower by two orders of magnitude, it does not appear to be in serious competition with the mercury ion standard for use as a primary standard, but it is useful for comparisons of optical standards. In the past year, quenched cooling of the calcium atoms has been implemented, and this reduces the linewidth from millikelvin to microkelvin levels. The short-term stability is 3×10^{-15} at 1-s averaging time. A new approach under consideration is to establish a lattice structure of 10^6 calcium atoms to reduce the Doppler effects even more. There are no major theoretical obstacles to this approach.

Substantial work is already under way in the development of a low-power chip-scale atomic clock with a total volume of 1 cm^3. Scaling laws for small (millimeter dimensions and smaller) buffer-gas cells are being studied using an apparatus that allows continuously variable spacing between two glass surfaces. Small gas cells have been successfully fabricated using glass capillary tubing, but efforts to make cells using silicon bonding to glass are not yet working. Success with the capillaries is sufficient to reach the first-year milestone for the project.

Time and Frequency Services

The Time and Frequency Services Group provides access to the division timescale via telephone and network time messages and radio transmissions from WWV, WWVB, and WWVH. The Internet Network Time Protocol servers at NIST now handle traffic of 1 billion hits a day, and the number continues to grow. The upgrade in transmitted power from WWVB has enabled a broad and growing range of low-cost mobile and consumer time products, which now function across the continental United States. Japan now has a station at the same frequency, which means that nearly common products can serve two markets. This capability will provide a natural stimulus for further commercial development.

Program Relevance and Effectiveness

The Time and Frequency Division at NIST represents an important and highly valuable capability of national significance. The services provided by the division are crucial to the users in commerce, industry, the scientific community, and universities. The supporting research and development is first-rate and relevant to the charge of the division.

As an example, this group maintains the division Web site, which is becoming the broadest and most valuable means of disseminating time and frequency measurement knowledge. Many of the technical papers produced by the division are available on the Web; soon all division publications will be available through this channel. A major benefit of the Web site is that it provides efficient and consistent answers to customers, who provide positive feedback regarding the site. The site also provides a venue for keeping the division informed of new directions in customer needs.

Finally, workshops and seminars presented by the division provide valuable service to the community. As an example, the NIST Time and Frequency Tutorial drew more than 50 people in 2002, including representation from many new sources such as DARPA and the Lincoln Laboratory. Survey data from this tutorial indicate high customer satisfaction.

Division Resources

Time and Frequency Division resources are growing at a reasonable rate, and the division continues to attract and retain high-quality personnel. It is staffed at a level sufficient to continue good progress on scientific and technical projects, and overall is reasonably well supported.

The retirement of a veteran investigator in 2003 will create a serious void in capabilities. As a transitional measure, this employee has agreed to remain as principal investigator for the PARCS project.

The self-admitted weakness of the division is in *continuous* operation of the primary standards. The NIST-F1 fountain was built in a hurry because NIST was behind in the international primary frequency standard community. NIST is now returning to upgrade the systems of NIST-F1 to improve its operational reliability. One member of the staff is focused on automation of NIST-F1. Burnout of staff is a concern, and the hope is that automation will reduce the potential for this problem and allow staff to focus on the design of the new fountain, NIST-F2. As a whole, the development of the primary standard could benefit from additional attention to applying good engineering practices when building or upgrading the clock.

The maser ensemble continues to serve as the operational flywheel for NIST-F1 evaluations. Noise in the timescale currently limits comparison of the Cs standard to the timescale. New hardware will replace masers that are more than 10 years old. New electronics have already improved the signal-to-noise ratio substantially. Finally, new software is being written to appropriately weight the clocks in the ensemble and produce the output.

Division laboratory space has been improved markedly. Two new laboratories with exceptional environmental controls have been constructed. These laboratories will house the laser and quantum logic work and have the best environmental controls on the site. Old space will be renovated and used for the fountains. New laboratory space for optical frequency measurements and the chip-scale clock project will be completed soon. There is a plan to renovate all division laboratories over the next 10 years. At this time, however, the cesium primary standard is housed in a laboratory with a leaky roof. The test and measurements laboratory is hindered by the interference of RF and microwave signals in the building, and is likely to be limited in its capability to conduct noise measurements with the needed sensitivities.

QUANTUM PHYSICS DIVISION

Technical Merit

The Quantum Physics Division makes up the NIST portion of JILA (formerly the Joint Institute for Laboratory Astrophysics), a joint institute with the University of Colorado. JILA is a multidisciplinary research organization whose principal researchers are the JILA fellows, about half of whom are university faculty members and half NIST employees. The mission of the division is to provide fundamental understandings of nano-, bio-, and quantum optical systems through investigations of new ways to direct and control atoms and molecules, measurements of chemical and biological processes and their interactions with nanostructures, and exploitation of interactions of ultrashort light pulses with matter. The partnership with the University of Colorado embraces a technical strategy to help produce a new generation of scientists. The overall aim is to produce world-class fundamental research with the potential to improve measurement science. This assessment covers only the Quantum Physics Division; the panel did not review all of JILA this year. Major thrusts of the laboratory and its achievements are discussed below.

Quantum Atom Condensates

The Quantum Physics Division has a history of recognized technical excellence in its areas of emphasis, which it continues to maintain and expand. It has been a leader in the field of neutral atom cooling and trapping and in the first observations of Bose-Einstein condensates (BECs) of neutral atoms, leading to the 2001 Nobel Prize in physics for two JILA fellows. Quantum dynamics of BECs continues to be a major area of strength for the division, with two NIST fellows maintaining innovative research programs.

The behavior of BECs is being explored in order to understand the nature of fundamental elementary excitations of these macroscopic quantum systems. In particular, angular momentum of a spinning condensate is trapped in a lattice of vortices; these vortices display interesting dynamics of their own, including phase transitions from translationally invariant "solid" phases to liquid phases in which the vortices undergo more complex dynamics and "striped" phases involving strong shear flows of atoms. Another possible state when the atom cloud evolves into a pancake-like quasi-two-dimensional state is analogous to the two-dimensional electron gas in solids that displays the famous quantum Hall effects. This analogy between dynamics of the BEC of atoms and related condensed matter systems is a major thrust of research that may shed new light on the behavior of both classes of systems and phenomena. Other ongoing research includes precision spectroscopy of ultracold atoms and the injection of a BEC into a lithographically patterned microstructure—a "BEC on a chip"—with the long-term goal of developing ultrasensitive inertial sensors using atom interferometry.

Another important area of ultracold atom research involves the study of degenerate Fermi gases of ultracold atoms, in which the quantum mechanics of fermions show interesting new phenomena, including the first observation of a Feshbach scattering resonance in fermionic atoms and potentially the formation of atomic Cooper pairs in an atomic superfluid phase. A new quantum condensate consisting of both cold Bose and Fermi atoms has also been produced and is being characterized.

Laser Stabilization and Control

The Quantum Physics Division has been a consistent pioneer of laser stabilization science and technology that has found its way into other NIST laboratories, into basic optical physics projects around the world, and into commercial laser products. Recent work has seen a significant extension of achievements in the area of laser stabilization with the development of laser frequency standards based on mode-locked lasers. This work, a collaboration of three NIST fellows, promises to revolutionize the field of optical frequency measurement by the introduction of methods to control to very high precision both the repetition rate and optical frequency, and ultimately the phase of trains of mode-locked laser pulses. The importance of this technology is that it extends the wavelength coverage of available precision optical frequencies tremendously and enables new techniques for the coherent control of optical fields. For example, it has enabled two mode-locked laser oscillators to be precisely synchronized for the first time, with a timing jitter in the femtosecond regime. This new level of control has already led to applications such as coherent anti-Stokes Raman spectroscopy (CARS) imaging (see below) at unheard-of sensitivity and signal-to-noise ratios.

Through the use of stabilized femtosecond frequency combs, it has been possible to transfer optical frequency standards from the JILA campus to the NIST Time and Frequency Division and vice versa using optical fiber links. Independent comparison can thus be carried out in the two laboratories, 7 km apart, of independently derived standards with a precision of 3×10^{-15} in a 1-s measurement.

Precision Spectroscopy of Cold Atoms and Molecules

The spectroscopy of atomic systems that may provide new frequency standards in novel ways is being explored using the stabilized frequency comb technology. Laser cooling of ^{87}Sr atoms appears to be the best path to a neutral atom frequency standard. In another project, OH molecules are being cooled via supersonic expansion and then slowed electrostatically for trapping in an electrostatic trap, providing the first opportunity for experiments on an ensemble of chemically interesting cold molecules.

Quantum Dots

Developments in apertureless near-field-optical-microscopy techniques have been exploited using quantum dots, showing the power of the method to enhance the fluorescence of very small objects of 3- to 6-nm dimensions. The new developments greatly extend the earlier ones made using molecules embedded in polystyrene spheres. A tapping mode atomic force microscopy method has been demonstrated to enable placing the probe nearer the sample, enhancing resolution and sensitivity.

Ultrafast Carrier and Spin Dynamics in Semiconductors

Many proposals to implement quantum information processing in solid-state systems suggest that coherent spins or excitons in semiconductors could be used to transmit and process quantum bits. Exciton coherence in GaAs is strongly influenced by many-body and phonon scattering effects and is complex to measure and to model theoretically. Likewise, spin coherence is lost through a variety of mechanisms operative in a range of doping and excitation conditions. Experiments in the Quantum Physics Division seek to provide fundamental measurements of these processes that would facilitate advances toward useful quantum information processing concepts and toward the realization of "spintronic" devices, which use the spin of the carriers rather than the charge for the transport of information.

Femtosecond Comb

A major development is under way to exploit the frequency techniques developed in JILA in order to effect quantum control in a unique way. In contrast to the electronics arena, in the optical field, phase control of pulses has been difficult to achieve and employ. Through outside support, the comb methods are being used to enable the relative phases of ultrashort pulses (e.g., 6 fs) to be controlled, ultimately allowing the synthesis of arbitrary pulsed optical fields. These methods will be useful in new approaches to quantum control and nonlinear optical processes.

Biological Physics

Biological physics is a relatively new area for the Quantum Physics Division. It is an inherently cross-disciplinary field, offering a significant opportunity for JILA to interact strongly with other members of the University of Colorado community. There are basically four projects that have a biological emphasis at JILA:

1. *Single Molecule Imaging and Sub-nanometer Resolution.* Measurement of the position of proteins bound to DNA in a time-dependent manner is being pursued in a newly constructed laboratory facility at JILA, and a number of collaborations have been developed with biologists on the University of Colorado campus who have interesting systems to study. The way should now be clear for exciting studies on the single-molecule dynamics of highly sophisticated proteins that process DNA molecules, allowing studies of the detailed manner in which single molecules interact with DNA and perform some of the fundamental steps of gene expression and control.

2. *CARS on Single Cells.* CARS is a potentially zero-background, spectrally sensitive imaging technique that can produce images of the distributions of molecules on a microscopic surface or volume. The molecules are selected by resonant scattering of unique vibrational transitions. JILA investigators have demonstrated the imaging of lipid molecules on cell surfaces, a very important subject in under-

standing signal transduction in cells. This technique is enabled by the availability of synchronized, frequency-stabilized femtosecond lasers developed at JILA, which allows near shot-noise-limited detection sensitivity. This project is a collaboration with Harvard University.

3. *Biomolecular Fluorescence Microscopy and Conformational Dynamics.* The use of a high-numerical-aperture confocal microscope is enabling the conformational dynamics of single biomolecules to be probed employing polarization resolved fluorescence detection. The dynamics of the molecules are extracted via time-correlated single-photon counting. Particularly valuable and detailed information is being gained on the fluorescence-resonant-energy transfer between donor and acceptor dyes on a single DNA strand, and by time-resolved polarization effects.

4. *Dynamics of Single DNA Molecules in Gels.* The dynamics of DNA molecules is being studied using high-speed, single-molecule imaging. Gel electrophoresis is a cornerstone technology of molecular biology, and key aspects of how electrophoresis of long DNA molecules occurs are still not understand in detail.

Program Relevance and Effectiveness

The Quantum Physics Division, along with its JILA partners, provides innovative fundamental advances at the frontier of science that are of interest because they have high potential for future advances in measurement science and technology. The division also continues to refine technology of proven utility to NIST measurement science programs, such as advanced laser stabilization methods. Further, the division provides a pool of talent that can respond to special needs in response to homeland security. For instance, one NIST fellow is actively pursuing methods for the sensitive laser-based detection of anthrax spores.

By virtue of its association with the University of Colorado, the division has access to a talented pool of graduate students and postdoctoral researchers, and among the most valuable products of the division are the talented and capable scientists that it graduates into positions with other divisions of NIST, in industry, and on university faculties. At least 47 JILA graduates have moved on to employment within NIST.

The division has been effective in strengthening its existing core areas of emphasis, with continued pursuit of the frontiers of understanding through experimental programs, including those in the areas of cold atoms, precision spectroscopy and frequency standards, quantum phenomena such as BEC, and advanced laser control and stabilization. New areas of potential importance have been identified (e.g., biophysics, quantum information), and strategies have been developed for making significant initial contributions toward ultimate leadership. The panel perceives a general overall evolution of the strengths of the division in response to changing needs for measurement science and the fundamental research needed to support future measurement science.

The Quantum Physics Division is active in collaborations with university groups, industry, and other NIST sites. Examples include the development of CARS imaging of living cells with a Harvard group, the advancement of short-pulse generation by means of laser stabilization and control with an MIT group, and the comparison of optical frequency standards with the Time and Frequency Division, made possible by a fiber link to that division.

The Quantum Physics Division is fundamentally a basic research and student education facility, and it performs these functions very well, as shown by its excellent record of scientific publications and presentations and by awards recognizing its accomplishments. In addition to the past Nobel Prize in physics, division researchers have recently been awarded the Max Born Award of the Optical Society, the Presidential Rank Award from the U.S. Office of Personnel Management, the William O. Baker

Award of the National Academy of Sciences, the Maria Goeppert-Mayer Award of the American Physical Society, and the Presidential Early Career Award for Scientists and Engineers, and one was named among the "100 Top Young Innovators" by *Technology Review*.

The development of the stabilization and synchronization of femtosecond pulses from two lasers has had an immediate impact with the commercial femtosecond laser producers, which have enthusiastically adopted the technology. The importance of mode-locked laser stabilization to the many applications of these lasers in chemistry, physics, and biological science and to the manufacturers of these laser systems has emphasized the need for a clear intellectual property policy that is known and understood by the NIST scientists. The lack of such a policy has been a significant impediment to the dissemination of this technology to the laser community, and it has resulted in significant misunderstanding among JILA scientists as to the ownership of intellectual property. The division has taken the initiative in opening a dialogue with NIST intellectual property lawyers to clarify these issues, but much work remains to be done in order to define a set of principles that can guide NIST scientists in these matters on a routine basis. *This panel cannot emphasize too greatly the need for clear intellectual property policies and procedures to facilitate effective interactions with industrial partners.* Intellectual property information should be summarized in a simple set of guidelines that staff members can understand and follow. The staff should also have direct access to Intellectual Property Department personnel for the resolution of specific issues that arise during the patenting process.

Biological Physics has three basic sectors: fundamental research, applied biotechnology, and biomedicine. The four projects now under way at JILA are in the fundamental research sector, although there are certainly avenues that will lead to applications in biotechnology and biomedicine. However, the training of a new generation of biological physicists is very important as biology becomes ever more sophisticated; JILA will act as an important source of young scientists with strong "hard science" backgrounds, moving into biology using the tools of physics and related fields. The effort in biological physics clearly identifies a new area of potential importance and a strategy for making significant initial contributions toward ultimate leadership. There are few physicists at present who have significant training in biological problems, and they will be essential for future growth in this discipline as biology continues to grow in sophistication.

Collaboration among JILA projects is an important component of the division's environment. Such collaborations exist in the areas of cold atoms and quantum condensates, application of stabilized femtosecond lasers, and biophysics. In biophysics, there are strong efforts to collaborate with the very strong programs in biology at the University of Colorado, and the potential is great for the biologists to begin to address important questions about how biomolecules function at the level of life processes. Closer collaborations within JILA of the three people involved in biological physics would be beneficial.

Division Resources

The Quantum Physics Division continues to nourish and build a highly qualified staff for the performance and extension of its capabilities. A new NIST fellow was hired this year with expertise in the physics of electrical circuits, quantum coherence effects, and quantum computing with superconducting tunnel junctions. This new endeavor brings another potentially important perspective to the division. Building on recent past accomplishments, it has been demonstrated that at low temperature, electrical circuits can be modeled in terms of quantum coherence for high-impedance objects. The ability to make transitions between states with varying numbers of Cooper pairs has been shown. Promising activities that are being pursued offer the prospect of producing entangled states of electrical circuits, the ability to do single-electron counting, the development of faster electron-counting methods, and achieving new developments in nanoscale circuits such as circuits that could be assembled using carbon nanotubes.

In last year's assessment, the panel raised important and disconcerting issues about the relationships between the Chemistry Department at the University of Colorado and JILA, brought to the fore by the loss of a valued senior NIST-JILA fellow. The panel was very pleased to find that both organizations have made a concerted effort to address this issue and that past problems have been very amicably resolved, to the benefit of both parties.

The current level of job satisfaction among NIST fellows seems very good. The 10 NIST fellows interviewed in this assessment uniformly praised JILA as a wonderful environment in which to do science, to the extent that those most sought after have rejected excellent offers from other prestigious institutions because they feel that JILA offers the optimum atmosphere, infrastructure, and opportunities for interactions with colleagues and for collaborations that allow them to be more creative and efficient in following up on their ideas than would be possible elsewhere.

Recruitment efforts have been very active in identifying strong candidates in biophysics and cold atom condensates that would add breadth and creativity to the JILA programs in both these areas. It is apparent to the panel that the division has been proactive in strengthening its core activities. Recruitment of top-flight researchers will remain a priority as several senior NIST JILA fellows reach retirement age in coming years.

The lack of sufficient laboratory space continues to be a concern for JILA. When the existing building was originally constructed, provision was made to create additional space by adding stories. Partial funding for this project from NIST and the university seems to be in place. The panel strongly recommends that this expansion be aggressively pursued.

Biological physics as practiced at JILA provides a rather challenging combination of facility support issues. JILA is well prepared to address some aspects of this challenge: that is, vibrationally quiet spaces for high-resolution imaging, very well managed clean air flow, and room temperature control. More difficult challenges will be the development of an appropriate wet-lab space, to include placement of chemical fume hoods, incubator space for cell cultures, adequate provisions for glassware cleaning and storage, and wet chemical benches. Ultimately, issues of homeland security involving biowarfare may require the construction of secure biological rooms with controlled access and guaranteed negative air pressure. It might well prove useful for future growth in such a broad field to consider putting biological physics facilities in a well-defined floor of JILA to facilitate interactions, to share common facilities, and to restrict access to potential biohazard areas.

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Materials Science and Engineering Laboratory: Division Reviews

CERAMICS DIVISION

Technical Merit

The Ceramics Division's mission is to work with industry, standards bodies, academia, and other government agencies in providing leadership for the nation's measurements and standards infrastructure for ceramics materials. During 2002, the Ceramics Division, in response to ongoing funding challenges, eliminated low-priority projects, reduced its total number of personnel, and reduced permanent staffing by 10 (a 25 percent reduction in force). The panel reviewed the process used to eliminate projects, and it concurs with the division's assessment and actions. The division also reorganized the remaining programs and personnel into four groups: Electronic and Optoelectronic Materials, Characterization Methods, Data and Standards Technology, and Nanomechanical Properties.

The panel reviewed six division programs (composed of 16 projects) in detail for their performance during 2002: Advanced Manufacturing Methods, Data Evaluation and Delivery, Materials Property Measurements, Materials for Opto- and Microelectronics, Materials Structure and Characterization, and Combinatorial Methods. The panel's overall opinion is that the division not only maintained the quantity and quality of its technical output during a difficult year, but is also in a better position to increase its output during 2003. Overall, the Ceramics Division published 120 publications in FY 2002 (86 in archival journals), which represents 20 percent of all MSEL's publications.

The following subsections discuss and evaluate the technical merit of the work in progress for each program.

NOTE: Chapter 6, Materials Science and Engineering Laboratory," which presents the laboratory-level review, includes a chart showing the laboratory's organizational structure (Figure 6.1) and a table indicating its sources of funding (Table 6.1).

Advanced Manufacturing Methods

The Advanced Manufacturing Methods Program included two projects: Process Modeling for Low Temperature Co-fired Ceramics (LTCC; eliminated in 2002) and Rolling Contact Damage/Fatigue. The objective of the LTCC project was to model the sintering processes in order to enable predictions of the distortions that occur during the manufacture of LTCC products. In last year's panel report, it was noted that the microstructure scale of the modeling approach (approximately hundreds of microns) might preclude translating the results to the much larger-scale distortions—for example, camber (bending)—of manufacturing interest. The technical output from this project was also low in 2002 (one conference paper), and during the year the division chose to terminate the LTCC project as part of its restructuring. Under the circumstances, the panel does not disagree with this action.

In the Rolling Contact Damage Fatigue project, an International Energy Agency task has been established to conduct an international round-robin comparison of rolling contact fatigue test methods among U.S., Japanese, and German participants. For the three-ball test, there appears to be the need both for better instrumentation to understand the range of applicability of the test and for carefully controlled measurements to provide a more scientific basis for the test. If this project is to be continued, such additional levels of rigor will be essential.

Data Evaluation and Delivery

The Data Evaluation and Delivery Program is focused on linking disparate structural and property databases to provide a basis for understanding existing materials and potentially for designing new materials. Most materials databases focus on a specific area, such as structure, properties, or phase equilibrium. However, most questions of current interest to the scientific and industrial communities do not concern one particular area, but rather the relationships between areas (e.g., structure and properties). Most exciting is the possibility of having quick access to information on a vast array of structures and properties simultaneously in order to postulate properties of structures not yet synthesized.

In keeping with the goal of achieving such a capability, one of the objectives of the Data Evaluation and Delivery Program is to enable seamless transitions from one data set to another. The Materials Property Data project compiles data, for example, on the elastic properties, hardness, toughness, flexural properties, specific heat, and sound velocities of many inorganic crystal structures. Keeping the database current in any one of these areas is an enormous task. The current inorganic structural database consists of 65,000 crystal structures that are updated twice a year. These updates are derived from the primary literature and typically consist of 1,500 to 2,000 new entries each year. The individual entries are only the beginning, as the true value of the database can only be derived from being able to link different entries by similarities and differences. With so many updates required each year, the traditional method of manually checking individual entries for consistency has had to give way to more automated approaches. The panel heard plans for constructing software tools to automate critical evaluation of entire collections of data. The panel believes that more extensive tools for identifying trends in and outliers among the data sets would offer great opportunity for scientific discovery.

Materials Property Measurements

The Materials Property Measurements Program has always had a strong emphasis on mechanical behavior and has built a reputation for quality research in the area of brittle fracture. Some of this expertise is being summarized in a new NIST Practice Guide, *Predicting Mechanical Reliability for*

Brittle Materials. Lifetime prediction has become increasingly important in many industries, and such guides are invaluable to technology managers for creating studies that are statistically valid. This program consists of two projects: Mechanical Property Measurements and Microstructural Design.

In 2002, plans were begun to shift this program's emphasis from macroscopic behavior to a focus on nanometer-scale mechanical property measurements. Properties such as nanohardness and elastic property measurement on small-scale samples have implications for advanced technologies. For example, mechanical properties of thin films have broad applications in many industries, including electronics, automotive, aviation, space, and medical devices. The panel has strongly endorsed this shift in focus to an area that could greatly benefit from NIST expertise, particularly in terms of test method and standards development. Work is beginning on Standard Reference Materials for nanoindentation. No such SRMs now exist, despite the rapid growth in sales of these instruments. Finally, instrumentation and test methodologies are being developed for friction measurements at the nanometer scale. Such measurements are increasingly important in microsystems and nanodevices.

Materials for Opto- and Microelectronics

The four projects in the Materials for Opto- and Microelectronics Program are all heavily linked with other NIST divisions and laboratories. The first, Optical and Structural Characterization of Optoelectronic Semiconductors, is focused on stress and composition standards in AlGaAs films, optical properties of AlGaN, and also InGaAsN studies. The measurements in this project appear to be very precise and carefully analyzed.

The second project, Phase Equilibria and Properties of Dielectric Ceramics, is focused on fundamental materials properties of ceramic materials, from both empirical and first-principles points of view. The NIST team has a long-standing, solid reputation of scientific contributions, and 2002 was a particularly good year for research output, with many publications, invited papers, and even popular articles.

The third project is Phase Relations of High T_c Superconductors. This project, which also has a very good, long-standing reputation, was funded in part for several years by DOE. The reported phase diagrams reveal information critical to the successful development of those high T_c superconductors. The NIST efforts are highly leveraged with many outside collaborators.

The fourth project is Nanotribology, focused specifically on hard disk drives. Unique measurements and analysis techniques have been established—that is, a high-speed impact test, finite-element impact modeling, and carbon overcoat characterizations—that have yielded valuable information about the drive head and disk materials and behaviors in operation. Also in this program is a task called Characterization of Ultra-Thin Dielectrics. This task has focused on silicon oxide-nitride-oxide stacks for flash memory and on high-k dielectrics for small-dimension silicon devices.

Materials Structure and Characterization

The Materials Structure and Characterization Program is one of the larger programs in the Ceramics Division. Its primary objective is the development and the application of state-of-the-art instrumentation and measurement capabilities to advanced materials. This program operates, maintains, and develops unique facilities for materials characterization at the National Synchrotron Light Source at Brookhaven National Laboratory and at the Advanced Photon Source at Argonne National Laboratory. It is the panel's belief that there may be no better example of the leveraging of government investment in unique facilities among the widest-possible community. The instrumentation capabilities that this program has built are unprecedented in the field of structure determination of materials and interfaces. The technical output of studies using these instruments has immediate applications in science and technology. The investigations range among a wide variety of fields, such as advanced coatings, fuel cells, optoelectronic materials, and pharmaceuticals.

Projects in the Materials Structure and Characterization Program also focus on standards. The panel heard from staff about a project devoted to developing diffraction Standard Reference Materials for use in the 20,000 laboratory diffractometers worldwide. Specific emphasis is being given to providing such SRMs in thin-film form to assist the electronics industry in using diffraction data to analyze stress states and composition variations in deposited thin films. The NIST team is constructing diffraction equipment capable of first-principles measurements of lattice parameters on samples to be used for diffraction SRMs. This equipment will greatly increase the reliability of interpretation of user results and will make possible reliable comparisons of measurements taken from different instruments. Finally, the program has incorporated the Powder Measurements project that was in the Ceramics Division for several years. This project is now focused on measurements and SRMs for nanometer-scale particles. These materials are of increasing interest for diverse fields such as optical materials and pharmaceutics.

Combinatorial Methods

The Combinatorial Methods Program represents a small effort in the Ceramics Division but is part of a large effort in the MSEL. The unique contributions of the Ceramics Division team are a dual-beam, dual-target pulsed laser deposition system that is used to fabricate several inorganic films for acquiring library data; a high-throughput spectroscopic reflectometer with a bifurcated fiber-optic probe for rapid mapping of thickness and index or refraction; and a NEXAFS (near-edge x-ray absorption fine structure)-based imaging technique with submonolayer sensitivity.

Program Relevance and Effectiveness

The Rolling Contact Damage Fatigue project's identification of existing test methodologies that lack reproducibility and are not well understood provides opportunities for this program's increased effectiveness in the future.

The Data Evaluation and Delivery Program's effectiveness is measured primarily by direct sales of its databases or by visits to its Web site. During the past year, sales of Phase Equilibria books and CDs exceeded $100,000, and the Ceramics Property Database was NIST's eleventh most active Web site. The program's most significant accomplishment for the year 2002 was the issuance of a PC version of the Inorganic Structural Database. Much of this database is licensed to diffraction instrument manufacturers to install with the software in their instruments. There may be no better way to disseminate this database than to have it readily accessible when researchers obtain new structural data. Researchers in academia and industry often search among these structures when taking even simple powder patterns rather than having to synthesize or obtain standards to compare against. As the software tools for critical evaluation of data are fully developed, new avenues of distribution may be created.

The Materials Property Measurements Program had an active year in the standards area. ASTM test methods for machining effects on strength (C1495) were developed, and methods in fractography (C1322) and rectangular beam flexural strength testing (C161) were revised. The team also led a VAMAS (Versailles Project on Advanced Materials and Standards) study group on an international, interlaboratory comparison of indentation test procedures on thin-film specimens; developed an instrument to observe in situ crack evolution and determine the critical load to produce damage of dental bilayers; and developed a stereological technique to measure distributions of grain boundary configurations. These grain boundary configurations will be used in NIST object-oriented finite-element analysis software.

Under the Materials for Opto- and Microelectronics Program, the careful work in the Optical and Structural Characterization of Optoelectronic Semiconductors project is definitely relevant to industry needs, in terms of both the materials chosen for analysis and the characteristics studied. The level of effectiveness of the work will be judged by publications, specific industrial interactions, and SRMs. The panel encourages increased dissemination of results from this good technical work. For example, the Phase Equilibria and Properties of Dielectric Ceramics project has selected relevant materials systems for study and has aggressively reported quality results to the technical community. In the Phase Relations of High T_c Superconductors project, focusing on tape materials/interface issues as a future direction is important for conductive tape applications of interest to DOE. The significance of the Teratology of Hard Disk Drives project to the drive industry and its suppliers is shown by the industrial donations of equipment, personnel, and funding that the project has received over several years. A remarkable number of invited talks have also resulted from this work. The Characterization of Ultra-Thin-Dielectrics project identified several companies as potential customers of the NIST research, but the project would have increased impact if direct contact were made with those companies to ensure that the scientific studies are addressing the most important issues in the industry.

The Materials Structure and Characterization Program, through its beam-line facilities, has been involved in several high-profile structural characterization studies during the past year, including characterization of nanoparticle assemblies with number density gradients and measurements to help unravel the solid-state physics of magnesium diorite superconductors. Across a wide range of topics, the SANS (APS) (small angle neutron scattering [Advanced Photon Source]) facility was used by 62 universities, 32 government laboratories, and 9 industrial users, leading to 28 archival NIST papers, 22 invited talks by NIST scientists, and 51 papers by the facility's users. The National Synchrotron Light Source was oversubscribed by more than a factor of two.

Division Resources

As noted at the beginning of this chapter, the staff of the Ceramics Division was reduced by 10 people in 2002 (four retirements and six reduction-in-force actions). The division was led by an acting division chief for most of FY 2002, and a new division chief was appointed in early calendar year 2003. While the panel concurs with the decisions made by the division management team, there is concern that the basic fundamentals that caused the financial circumstances of 2002 have not changed—specifically, that mandated increases in salary without a concomitant increase in base funding will distort the distribution of spending between salary and other object codes.

MATERIALS RELIABILITY DIVISION

Technical Merit

The mission of the Materials Reliability Division is to develop and disseminate measurement methods and standards that will enhance the quality and reliability of materials for industry. The division is organized in three groups: Microscale Measurements, Microstructure Sensing, and Process Sensing and Modeling. However, the division's technical programs cross disciplines and are better grouped according to the division's centers of excellence in technical focus areas: Micrometer-Scale Reliability, Nanotechnology, Biomaterials Metrology, Infrastructure Support, and the World Trade

Center investigation. These technical focus areas are well aligned with those outlined in the overall NIST Draft Strategic Plan (the NIST 2010 plan) and highlight the division's unique capabilities for addressing reliability issues in these emerging areas.

The Micrometer-Scale Reliability project works on understanding and predicting failure modes in a variety of material systems under constrained geometries and scaling effects. This project also studies the roles of stress, strain, and temperature in microelectronics and photonic devices. It continues to apply and develop methodologies for measurements of state-of-the-art materials. Further advances were made in the development of pattern-plated materials to study the mechanical behavior of electrodeposited thin films. AC-stressing methods for the fatigue testing of fine-scale metals were used. In addition, the team advanced its work in thermal scanned-probe microscopy methods for determining damage mechanisms associated with thermomechanical loading and applied electron backscatter diffraction methods for elastic strain field mapping.

The Nanotechnology project works to develop metrologies for nanoscale properties and studies the physical properties of thin films and nanostructures. The team has projects in Brillion scattering for thin-film analysis, conductive atomic force microscopy using carbon nanotubes, atomic force microscopy, nanoscale modeling, mechanical properties of thin films, thermal barrier coating evaluations, and X-ray methods.

The work of the Biomaterials Metrology focus area represents a new technical direction for the division; it aims to apply materials science to biomaterials research. The team is now concentrating on the mechanical properties of polymer scaffolds, cellular-engineering microsystems, and pediatric pulmonary hypertension. By consulting with biomedical experts at the University of Colorado Health Sciences Center and Colorado Children's Hospital, the team has identified a good match between its materials expertise and the critical research area of cardiovascular disease. A fully functioning biomaterials laboratory with advanced metrology capabilities has been established.

The team addressing the Infrastructure Support Program provides expertise in failure analysis and failure prevention for large structures. The team continues to be a leader in providing Charpy impact standards by making significant contributions to improving both the SRMs and the test. The staff also have strong international connections and are working toward setting an international standard for Charpy impact testing. The team provides service to the Bureau of Reclamation in metallurgical issues arising during inspections of water-retaining structures, such as the planned repairs to the Folsom Dam in California, and other evaluations for local municipalities. The team's expertise in weld repair and consumable development yielded repair procedures for cracks in the skin of the U.S. Capitol dome in FY 2002. Other activities include waveform-based acoustic emission methods beyond those commercially available for the study of transient-energy release and work in conjunction with the DOT and DOE to improve pipeline safety.

In support of homeland security, the work on infrarstructure support applies multidisciplinary skills in metallurgy, physics, and materials science to analyze the structural steel from the World Trade Center's Twin Towers and WTC Building 7. The team evaluated the chemical composition and microstructure of steel from the WTC and tested its tensile and creep behavior to evaluate how the material reacted to the extreme conditions produced in the tragedy. This work has been done in conjunction with the Building and Fire Research Laboratory and will support improvements in the design, construction, maintenance, and use of buildings in the future.

The division continued to excel during the past year with high technical merit and output—more than 60 publications, more than 20 invitations to make presentations at technical conferences, and two patents. The staff has received appointments to numerous journal and conference proceedings editorships and is represented on the American Physical Society's Keithley Award Committee.

Program Relevance and Effectiveness

The Materials Reliability Division continues to provide the national technical leadership required to address the broad range of materials quality and reliability issues that impact industry and the nation. The division houses world experts in a broad range of fields, from nanoscale metrology to large-scale structures. FY 2002 highlights include the continued development of the Biomaterials Metrology effort in support of the NIST Strategic Focus Area of Health Care and the response to the World Trade Center investigation. The panel was very impressed with the progress made within the year in the Biomaterials Metrology project, establishing an impressive set of programs in cardiovascular disease that exploit the division's advanced expertise in metrology in a new direction for the division. In the WTC investigation, the division became a key player in the metallurgical work, applying its capabilities, which are unique among NIST resources, to provide the very rapid response required.

In FY 2002, the Materials Reliability Division responded very effectively to the panel's recommendation to focus the division around its core competencies and the key SFAs. The reorganization of the division into centers of excellence—Micrometer-Scale Reliability, Nanotechnology, Biomaterials Metrology, Infrastructure Support, and the World Trade Center evaluation—has allowed the division to break down some organizational barriers that were present under the previous structure and to utilize resources better across the entire division. The division continues to do novel and important work for the microelectronics and photonics industries and is now extending its influence into health care with the establishment of its new thrust into biomaterials metrology.

The division has a broad range of customers from industrial partners, to governmental agencies, to national laboratories of other countries, to academic institutions. The division is focused on developing tools and metrics that can be used by its partners, and it serves as an active center for measurements. For example, the division worked with collaborators to disseminate its work in thermal-scanned probe microscopy for packaging reliability. The panel approves these efforts to ensure that the division's work is aligned with the SFAs and that it is useful for its many partners. However, the panel believes that in some projects the division is too often in a supporting role within MSEL and not directly connected to the industry partner. The panel maintains that even in interlaboratory collaborations, direct connections between division personnel and external customers would be beneficial in order to effect a more efficient introduction of the division's developed technology to the appropriate industries. The panel is also concerned that the division is not compensated for its measurement services and recommends that it look for "best practices" within NIST and the MSEL to determine a way to be compensated for measurement services provided to companies.

The Materials Reliability Division's rapid response to the World Trade Center disaster exemplifies the value of the division's unique technical expertise. The panel recommends that the division build on its success with the infrastructure reliability projects, including the WTC work in FY 2002, by proactively identifying exploratory projects that address other infrastructure reliability issues that could have significant impact on homeland security. The division offers a depth and breadth of experience in investigating material and structural failures that could not be easily or quickly replaced. As demonstrated in the WTC and Capitol dome investigations, it provides a vital body of expertise for quick response to infrastructure issues.

The program in Biomaterials Metrology has made rapid progress and is a good model for the division with respect to utilizing its core competencies in the SFAs. For example, an outside consultant was engaged to advise on key areas in health care in which the division's strong expertise could be exploited in developing metrology tools, micromechanical testing, and mechanical modeling; this action led to the rapid identification of important research areas in cardiovascular disease. The program's regular status meetings to review the research, obtain input from external experts, and solicit input from the bench level on keeping the program goals within NIST's SFAs are an admirable example of the collaborative nature of the projects in this program.

The division has a high level of relevance and effectiveness as evidenced by the large number of papers published in journals, the awards received by the researchers, and the number of Web site downloads. Many of the projects, such as those within the ATP and Director's Choice Awards, have direct measures of effectiveness with well-defined milestones. The panel believes, however, that some projects, especially the base-funded programs, could benefit from clearly articulated milestones and from regular status reviews of progress toward the milestones. Strict milestones may not always be appropriate for long-term research projects, but the panel recommends that projects be reviewed within a flexible structure. Regular reviews with group leaders could determine if progress was satisfactory, if milestones were being met, if the project was within the original scope and within the SFA, and how project goals should evolve. This process might also help in effectively using resources in a flat budget environment.

The majority of the Materials Reliability Division's research programs are long term, but their focus changes in response to customer needs and the requirements of NIST. The long-term research programs provide not only technical leadership in their respective areas, but also expertise that can be called quickly into action, as evidenced by the homeland security activities.

Division Resources

Although the Materials Reliability Division has maintained strong technical leadership in its areas of expertise, the panel is concerned with the continually declining number of permanent staff. The division has done a good job of meeting staffing needs creatively within a flat base budget, but this has been achieved primarily through temporary appointments and the use of nonpermanent staff. The continued erosion of the permanent staff base will jeopardize critical efforts such as succession planning and maintaining a strong base of permanent experts. The panel is also concerned with the slow pace of the search efforts targeted toward finding a replacement for the retiring division chief.

With the retirement of the current division chief and the inevitable management changes to the organization, maintaining continuity in the current focus of the division is strongly recommended. After 2 years of realignment within the division toward a more focused mission, core centers of excellence, and programs well aligned with the SFAs, the division is just starting to produce the results that these changes were meant to promote. Among the workforce in the division, the changes seem to have had a positive impact as evidenced by the results of the NIST employment survey in which the division staff rated their work environment and their relationship with the division management very favorably. In general, their responses to these types of questions about such issues were more favorable than were the responses from NIST overall. The panel feels that a clear message from the division management assuring staff that the current focus will continue is essential.

While the changes within the division have been very positive in increasing cross-functional interactions with the Gaithersburg divisions, the panel would like to see more interaction between the MSEL management in Gaithersburg and the Boulder staff, either through on-site visits or telecommunications.

The NIST policies and processes on intellectual property appear not to be communicated effectively to the staff. The NIST counsel's office appears to respond well only to "boilerplate" issues, and the staff tends to avoid using the intellectual property mechanisms in place because of both perceived and real barriers. The panel recommends a review of the policies in order to establish a more user-friendly process.

Facilities for the division in Boulder have not improved significantly, although the staff has managed to work within the constraints of the laboratories and has done an admirable job of setting up new laboratories and equipment within the existing facility. However, as the research activities probe ever smaller length scales, apparatus must be made extremely stabile against vibration. Most of the facilities available to the division cannot currently meet this requirement, and so on-grade offices must be converted into laboratories with the attendant lack of regular laboratory outfitting.

The panel recommends follow-up on its recommendation from last year for the development of a critical, "must-have" list of capital equipment needed to maintain the division's status as a worldwide center of excellence in materials reliability. Within the constraints of 1-year, use-it-or-lose-it capital budget cycles and the need to purchase major pieces of equipment that may require more dollars than are available in a single year, the panel recommends that the division explore alternatives to acquiring costly but critical equipment—for example, equipment leasing options.

METALLURGY DIVISION

Technical Merit

The Metallurgy Division provides critical leadership in the development of measurement methods, standards, and fundamental understanding of metal behavior. This information is needed by U.S. materials producers and users in order to provide materials needed for existing and emerging technologies.

The division is organized in five groups on the basis of materials class and category of expertise: Electrochemical Processing, Magnetic Materials, Materials Performance, Materials Structure and Characterization, and Metallurgical Processing. Individual programs are not confined to the group structure and typically span more than one group and frequently more than one division of the Materials Science and Engineering Laboratory. This matrix structure provides great flexibility in program definition, makes possible the assembling of the spectrum of expertise required for each program, and encourages strong collaboration between groups and divisions. This strong collaboration across groups and the supportive environment are among the truly remarkable characteristics of the Metallurgy Division and the NIST MSEL in general and a true strength of this laboratory. The consensual process in choosing programs and priorities is one of the principal factors engendering the exceptionally high morale of this division, even in the face of essentially static budgets and numbers of permanent staff.

The division's particular technical strengths are in diffusion, phase transitions, structural characterization, and modeling, and, in special areas, synthesis. The programs of the division can be divided into three broad categories:

1. The development and promulgation of standards, especially measurement standards, in mature areas of technology;
2. The development of scientific understanding in areas of technology of some maturity that are challenged by advances in materials or processing demands; in such areas—materials processing being one—current empirical approaches are not adequately extensible, and deeper fundamental knowledge is required; and
3. The exploration of new areas in which it is perceived that industry will in the foreseeable future require knowledge and support.

An example in category 1 is the International Hardness Standard Program, perhaps the best present current example of a traditional NIST standards program. The new-science content is modest, but the need for standardized measurement techniques and standards reference samples is great. The effort in unifying the Rockwell-C hardness scales makes NIST the world leader in that field, and the *Rockwell Hardness Measurement Practice Guide* (available on the division's Web site at www.msel.nist.gov/practiceguides/SP960_5.pdf) is a logical and valuable output.

An example in category 2 is the Light Metals Forming Program in its various facets. As the automobile industry moves to lightweight bodies with new alloys such as ultralight high-strength steel and more formable aluminum sheets, there is a greater need than in the past to understand formability and springback issues related to stamping operations. Currently, the automotive industry has the capability to determine the relevant process parameters through numerical simulation. It is, however, a difficult task to fully understand the microstructural mechanisms that govern the plastic deformation of the materials. NIST scientists have provided invaluable experimental data as well as material modeling support to the original equipment manufacturers. In category 2, industry has encountered problems and is looking to NIST to provide a deeper understanding of the root causes of problems.

Examples in category 3 are the Ballistic Giant Magnetoresistance project in magnetics and the Nitride Metallization of Optoelectronic Devices project in microelectronics. In both cases, the Metallurgy Division is anticipating areas of probable technological and scientific need. Such work entails high risk but potentially high payoff.

The exceptional overall materials expertise residing in the Metallurgy Division enables it to marshal a strong effort in newly activated programs, as was observed with the World Trade Center investigation.

Program Relevance and Effectiveness

The Metallurgy Division's customers represent a wide range of industries, as well as universities. The most obvious and dominant customers are the automobile, aerospace, and magnetic data storage industries and the portions of the electronics industry involved with electrodeposition and interconnect. With the exception of the electronics industry, these tend to be mature industries, a subject that is discussed below.

The evidence is strong that the division's programs are relevant to the current and future needs of its customers. Programs are typically formed through a pull by the industry and concurrent analysis of its technology and problems. Areas are then identified in which the scientific strength of the division positions it to make special and unique contributions to the specified technologies. Examples of this approach abound, such as that of the lead-free solder, superconformal film growth, and the metal springback and formability programs. The Ballistic Giant Magnetoresistance and the Optoelectronic Nitride Coating projects address future industrial needs.

The division does an excellent job of preserving a core competency to be applied to real problems. In response to questions arising from the World Trade Center building collapse, in-house expertise was marshaled to develop a high-deformation-rate, high-temperature experimental system to address a new set of needs arising from the analysis of this incident.

There is abundant evidence that the results of the division's research are being disseminated to and are utilized by industry: for example, the ongoing demand for Standard Reference Materials and standard samples; the large number of hits on the division's Web site; letters of appreciation from industry; collaborations on specific issues; and the many instances in which collaborating companies, or simply industry-associated companies, have incorporated NIST results into their ongoing development efforts. In a number of cases, the output utilized by industry is an improved model of the behavior of interest and the generation of reliable input parameters for existing or new model systems. Recently, the automotive industry has looked to NIST to provide a deep scientific understanding of material behavior during plastic deformation and the know-how to turn such understanding into mathematical models for use in simulations. The division staff clearly works hard at making contact with its customers and communicating useful results to them.

Overall, the panel believes that the programs of the Metallurgy Division are well attuned to customers' needs. The panel is concerned, however, that in some instances links to applications could be stronger. In the Plastic Deformation Program, for instance, the roughness project would benefit from more user input, and in the phase diagram arena, the extension to systems of 10 or more components, while a tour de force, is probably not as useful as more attention to ternary or quaternary systems.

Division Resources

Funding for the Metallurgy Division has been essentially flat for several years. Given mandatory salary increases and the rising cost of expendable and support personnel, the size of the full-time equivalent research staff has diminished significantly over the past decade. The panel notes with approval that the decline has been halted in the past 2 years and may be slightly reversed. The panel notes also that the funding per full-time employee is roughly $200,000, including overhead (out of which capital purchases are amortized). This funding, though certainly not overgenerous, is also certainly adequate.

The principal complaint by the staff, and a valid one, is the difficulty of acquiring capital equipment. For a laboratory that has the responsibility for setting national and world standards, it is important that the equipment be state of the art. This is frequently not the case. To acquire a major piece of equipment, such as a focused ion beam system or transmission electron microscope, it is necessary for three or four divisions to pledge most of 1 year's capital budget to that purchase. There is no apparent escape from this capital resource shortage within the present budgeting process. A one-time-only capital grant of significant magnitude, and outside the present requirement for amortization by the operating budget, would be of enormous benefit to the Metallurgy Division and the Materials Science and Engineering Laboratory as a whole.

The core value of the Metallurgy Division is the competency of the permanent staff. The key challenge to the division management is to maintain a central competency capable of executing the division's mission with respect to both present and future needs.

The panel has some concern that the primary customer base of the Metallurgy Division is waning industries (automotive, steel, aluminum, aerospace). The question then arises as to whether the division should be moving actively to dissolve the present core competencies and to replace them by more modern competencies, such as those that underpin the information revolution. The panel is in unanimous agreement that such an accelerated dissipation of the present capability would be an enormous mistake. The division's competency in the essential disciplines of metallurgy is unique in its breadth and strength and is in its own right a national treasure.

The value of the core competency in metallurgy was demonstrated recently by the role that the division has been playing in analyzing the collapse of the WTC's Twin Towers. There is no other group to which the nation could turn for equivalent expertise in this effort. In a nation with an aging infrastructure—for instance, its bridges and pipelines—such expertise may be essential not only in analyzing future structural failures but also in devising strategies to minimize such failures. The panel foresees also that the Metallurgy Division will be called upon in the near future to generate similar programs in support of the homeland defense mission. The staff of the division must, over time, be updated with young employees, but turnover at the rate of one staff member per year seems an appropriate pace. In hiring new staff, however, the division must make sure that it is acquiring the expertise to support emerging industries, not restricting hires to replacing, more or less in kind, present areas of emphasis.

POLYMERS DIVISION

Technical Merit

The mission of the Polymers Division is to provide the measurement methods, standards and emerging materials science testing and measurement to facilitate the development of technology in support of the manufacture, commerce, and utility of polymeric materials. The division consists of five core groups: Characterization and Measurement, Electronics Materials, Biomaterials, Multivariant Measurement Methods, and Processing Characterization. Additionally, the division manages a NIST/NIDCR (National Institute of Dental and Craniofacial Research) interagency program on dental materials. The division continues to refocus its resources into cross-group projects that meet the Strategic Focus Areas of NIST (including Nanotechnology and Health Care) and emerging needs in polymeric materials measurement technology. Significant advances in key technologies as discussed in the following subsections have ensured the maintenance of the high quality and technical merit of the Polymers Division's efforts through the review period.

Characterization and Measurement

In the Characterization and Measurement Group, the Multi-Scale, Multi-Modal Imaging and Visualization project represents an emerging capability that will couple the output of real-time, quantitative, nondestructive optical measurement techniques with pattern recognition to provide the researcher with "immersive visualization"—that is, the ability to "climb inside" a molecule or system to study the structural and functional interactions controlling properties of interest. Key goals are being achieved, the resolution and speed of optical coherence microscopy has been improved into the required target zones, and chemical functional imaging techniques such as coherent anti-Stokes Raman spectroscopy are slated to be developed. Several collaborations with other divisions and laboratories are providing additional analytical and computing capabilities. The application of this new technique is to characterize scaffolds for tissue engineering.

The Characterization and Measurement Group maintains world leadership in the field of polymer mass spectrometry, with special emphasis on polyolefin systems. Major technical accomplishments include the production of an intact gas-phase polyolefin ion six times higher in molecular weight than previously reported, and the development of a data analysis algorithm for peak molecular weight. Outreach to the polymer mass spectrometry community has been strengthened through close relationships with equipment manufacturers and through informational meetings, extensive use of the Internet, and many publications. The overall technical merit of this technique is well recognized. The polymer standards effort continues to provide the reference materials needed to calibrate the analytical instruments used to characterize polymer systems. New test methods are being developed in conjunction with other standards laboratories and organizations worldwide. In this area, the present focus is on polymer mass spectrometry as a method for the certification of primary molecular weight standards.

Electronics Materials

During the last several years, the Electronics Materials Group has worked very closely with industry and groups such as International SEMATECH to establish and obtain resources for the following three major projects in order to meet the most pressing needs for electronic materials and standard measurements.

The Low-k Dielectric Thin Film project has continued to develop and demonstrate new measurement methods for the structural characterization of low-dielectric constant thin films. Techniques such as X-ray and neutron porosimetry have been developed with strong support from industrial partners, including International SEMATECH. Several methods demonstrated in prior years have been successfully incorporated into the core characterization programs.

The goal of the Dielectric Characterization of High-k Materials project is to develop a new, high-frequency broadband dielectric test method for the thin-film dielectrics required for embedded passive devices. The first procedure evaluated in conjunction with IPC/IEEE and several industrial, government, and academic partners defined the need for new, high-frequency and high-voltage test methods. These are now being developed.

The Polymer Materials in Photolithography project has continued to seek new, high-resolution measurement methods to evaluate and develop the photoresists needed to fabricate sub-100-nm linewidths. The potential of small-angle X-ray scattering has been demonstrated as a leading candidate for the precise measurement of critical dimensions and line-edge roughness of lithographically patterned structures.

Overall, the technical merit of the Electronics Materials Group is well appreciated. A major challenge faced by all three projects is to transfer established test procedures to their customers, primarily industrial laboratories, in order to free up their resources to tackle the next pressing needs.

Biomaterials

The Biomaterials Group continues to make steady headway in broadening its mission beyond a traditional focus on the NIST/NIDCR interagency program on dental materials. The effort on dental materials, while maturing, continues to make progress in the design and characterization of amorphous calcium composites and in utilizing combinatorial methods to understand and optimize mechanical and physicochemical properties of composite resins.

A concerted effort has been made in the past year to leverage the Biomaterials Group’s expertise in restoration materials to address new areas of significance to the biotechnology and pharmaceutical industries. In this regard, the Biomaterials Group has established a robust effort in metrology at the interface between materials science and cell biology, both in the definition of relevant quantitative parameters and in the development of appropriate methodologies. Of note thus far is the progress made in characterizing the mechanical properties of scaffolds and scaffold-tissue hybrids, the functional imaging of tissue development in scaffolds, and nascent efforts in the quantitative measurement of inflammation in model systems. Exciting advances have been made in the functional imaging of tissue, using coupled and complementary techniques (e.g., fluorescence with optical coherence tomography, magnetic resonance with optical methods, multichannel fluorescence, and others). This effort is well advanced in its goal of offering multifactorial solutions to the problems of quantifying cell–material interactions. The development of these tandem imaging techniques will allow laboratories that rely on one of the metrologies to validate their methods and provide consistent comparison of materials across disciplines.

In conjunction with the Multivariant Measurement Methods Group, high throughput and combinatorial methods are being developed for the preparation of material libraries with properties measurements. An important goal here will be to define and prepare reference materials for the biotechnology industry that are outside the conventional expertise for this industry (such as mechanical properties, surface chemistry, and morphology and anisotropy). Key to these efforts is the ability to identify the specific needs of these potential customers.

Multivariant Measurement Methods

The Multivariant Measurement Methods Group is a relatively new addition to the Polymers Division and has shown excellent progress in the past year. Combinatorial synthesis has been well documented as a powerful method for new drug/chemical discovery. The Polymers Division has pioneered the concept for combinatorial (multivariant) testing. The current technical priorities are centered on the development of multivariant methods for adhesion, rheology, and mechanical and surface property evaluations. In the adhesion area, combinatorial testing protocols were developed to determine the peel strength of adhesives, adhesion to rough surfaces, and pressure-sensitive adhesive characterization. A novel method was demonstrated for determining the modulus of thin films based on buckling instability during compression. Prototype instruments based on lithographic fabrication methods have been developed for the determination of rheological, mechanical, and adhesion properties of materials having variable composition. The opportunities for these methods extend much farther than the Polymers Division has resources to support. The synergy between combinatorial methods and other projects in the Polymers Division (e.g., those of the Biomaterials Group) has been investigated, and biological cell adhesion as a function of gradient surfaces has been demonstrated.

Processing Characterization

The Processing Characterization Group investigates methods to improve the processing control and performance of polymeric materials and composites. The present projects are directed toward the nanotechnology thrust of NIST and include nanocomposite processing and nanoscale manufacturing. Molecular dynamics simulation has revealed a clustering transition in nanoparticle (carbon nanotubes)-filled polymers. This observation predicts a critical shear rate for effective dispersion. A technique based on "frustrated total internal reflection" with sensitivity down to 20 nm has allowed determination of the kinetics of fluoropolymer additive migration to the surface of polyolefins during extrusion. This is key for the elimination of flow instabilities as well as for allowing novel surface properties. Dielectric methods have shown promise as in-line sensors to ascertain the level of nanoparticle dispersions in polymer melts. Integration of processing and property measurements in single microfluidic devices is under development, with relevance to combinatorial experimentation.

Program Relevance and Effectiveness

The panel investigated the Polymers Division's project and program portfolio relative to the missions of the division and NIST missions and relative to the division's impact on technology areas and the industries it supports. It concluded that at the present time this portfolio properly balances these objectives and provides high levels of support and strong impact. The panel reviewed the recommendations of last year's assessment and found that the actions taken in response were appropriate. Specifically, to ensure proper balance between the addition of new division projects and "sunset" projects, the division has redirected projects that have run their course to initiatives that have or are envisioned to have greater impact. With this approach in place, the panel has confidence in the present and future of the division. In the newer areas of Biomaterials and Multivariant Measurement Methods, extensive collaborative efforts with external academic, industrial, and government laboratories are strong positive elements that will secure the relevance and effectiveness of these initiatives.

The question of specific metrics to determine effectiveness was discussed and will require further dialogue to better ascertain the success of new and emerging projects. In the past, it has been apparent to industrial review board members that the safety protocol at the national laboratories (including NIST) does not meet the typical, rigid standards of industry. The recommitment to safety noted in the Polymers Division deserves recognition.

In the Characterization and Measurement Group, the Multi-Scale, Multi-Modal Imaging and Visualization project has goals that, if achieved, will have a significant impact on the design and development of polymeric materials and systems. Excellent progress is being made. A $1.5 million, 3-year ATP grant was awarded to the project, together with MSEL's Ceramics and Metallurgy Divisions and the Information Technology Laboratory, to develop and demonstrate this new capability.

Over the past several years, the Characterization and Measurement Group has developed and demonstrated polymer mass spectrometry as a very effective tool for determining the molecular weight characteristics of polymeric materials. During the past year, the group has spent much time transferring this knowledge to industry. A workshop focused specifically on the needs of industry attracted 68 attendees, an annual meeting with a leading instrument supplier attracted more than 15 mostly industrial users, and a Web site that provides a database of methodologies for analysis of polymers by mass spectrometry has been set up. Standards are an important cornerstone for the continued development of polymer science and technology, and so the priorities of this project must be frequently assessed to meet emerging needs while still supporting well-defined needs. To this end, feasibility studies were initiated last year to provide standards for branched polyethylene, biomaterials for intraocular lens, and scaffolds for tissue engineering.

The NIST Biomaterials Group has the potential to occupy a unique niche at the interface between materials science and biology and to be highly relevant in the development of metrology critical to both commercial and regulatory practices in the biotechnology and pharmaceutical industries. The effort is still in its early stages, and continuous integration with the group's customers and with the various regulatory and policy-setting bodies will be critical to its success. One concern of the panel is whether the level of in-house biological expertise in the Biomaterials Group is sufficient in the short term to compete effectively in this area. The panel believes that this shortcoming can be addressed by exercising close cooperation with NIH and industrial laboratories.

The outreach of the Multivariant Measurement Methods Group involves a Combinatorial Methods Center with 14 external partners (13 of them are industrial). This center allows for the determining of relevant industrial needs (reflected in the choice of focus areas), the dissemination of information on design concepts, methods development in cooperation with real users, and the development of a database system integrating center instruments, analysis, and experimental design. The center is effectively acting as a catalyst to promote combinatorial testing in the academic and industrial technical communities. The potential of this approach in the evaluation of complex, multicomponent mixtures prevalent in industrial use (cosmetics, adhesives, coatings, and emulsions) could be as significant as the combinatorial synthesis techniques that are now well established. At present, experimental design is the only method available to rationally optimize complex mixtures. The center is making good progress toward accomplishing this goal. This project area has done an excellent job of disseminating information through publications, workshops, a Web site, and highly visible articles (e.g., in *Chemical and Engineering News*). The opportunities in biomaterials evaluation and electronics/optoelectronics can and will be extensive.

The project portfolio of the Electronics Materials Group was developed in conjunction with a wide range of industrial partners and industry groups, including International SEMATECH and IPC. Specific goals are reviewed regularly and are supported by these partners, and reports are provided to DARPA, ISMT, and IPC. This group is well recognized for its unique measurement capabilities, expertise, and technical quality. To date, the group has been very effective at providing creative solutions to meet the needs of its customers in a timely manner. To continue this success story, the panel recommends that the group transfer most of its demonstrated test methods to its partners.

The project priorities in the Processing Characterization Group have been shifted to nanoscale measurement and processing problems from larger-scale continuum studies. This change is in concert with a key NIST mission as well as external emphasis. In-line processing characterization of nanocomposite dispersions (under development) is a measurement technique that does not now exist and is needed for process control and optimization. It has been pointed out that the promise of polymeric nanocomposite technology is clouded by the hype that exists relative to the quantification of "nano" effects (deviations from continuum mechanics). NIST and the Electronics Applications Group can play a key role in ascertaining the specific advantages (and disadvantages) of nano-reinforcement of polymers.

Division Resources

The funding for the Polymers Division appears consistent with division goals. Significant renovation of the biomaterials laboratory is in progress, which is in line with recommendations to increase the division's capabilities and programs in this area. The division is planning to acquire optical coherence tomography to improve chemical-specific imaging abilities.

The Polymers Division continues to successfully recruit high-quality postdoctoral associates through the National Research Council's Postdoctoral Program. The panel is concerned, however, that there is not enough permanent staff in the Multivariant Measurement Methods Group to accomplish its tasks and reach its goals.

REVIEW OF THE NIST CENTER FOR NEUTRON RESEARCH

This annual assessment of the activities of the NIST Center for Neutron Research (NCNR), operating as part of the NIST Materials Science and Engineering Laboratory, is performed by the Panel for the NIST Center for Neutron Research. The report is based on a formal meeting of the panel on January 30-31, 2003, in Gaithersburg, Maryland, and on documents provided by the NCNR.[1]

The members of the panel are Eric W. Kaler, University of Delaware, Chair; Ian S. Anderson, Oak Ridge National Laboratory; Zachary Fisk, Florida State University; Charlotte K. Lowe-Ma, Ford Research Laboratories; Linda (Lee) Magid, University of Tennessee; V. Adrian Parsegian, National Institutes of Health; Philip A. Pincus, University of California, Santa Barbara; and Kenneth C. Rogers, U.S. Nuclear Regulatory Commission (retired).

Major Observations

The panel presents the following major observations based on its assessment of the NIST Center for Neutron Research:

[1]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *NIST Center for Neutron Research: 2002 Accomplishments and Opportunities*, NIST SP 993, National Institute of Standards and Technology, Gaithersburg, Md., December 2002.

• The NIST Center for Neutron Research is an essential national user facility with high-quality science, instruments, and reactor operations. Each of these elements is critical to NCNR's success, and plans to bolster the internal science programs with new funds and hires should be aggressively supported. The panel foresees a severe negative impact on the overall state of neutron science in the United States should funding to NCNR be further reduced. The organization is very lean and extremely well managed.

• The performance of NCNR relative to its mission has been excellent:

—The NCNR operates the NIST Research Reactor cost-effectively, with an enviable safety record.

—In some fields the NCNR scientific staff are considered to be leaders at the forefront in the development and application of neutron scattering.

—NCNR management has been proactive in recognizing and moving into new topical areas in which neutron techniques and new neutron instrumentation can have a valuable impact for the overall U.S. scientific community.

—The NCNR effectively serves a large community of researchers, as evidenced by oversubscription to the available instrumentation time.

• Reactor operations continue to be first-class. The panel is also pleased to note that relicensing plans are on track, and it commends the center's ongoing consultation with the Brookhaven National Laboratory to review preparation for relicensing. Nonetheless, a more aggressive stance toward maintaining corporate knowledge about the reactor is needed. This could be accomplished by more formally documenting instrumentation and by developing and maintaining an organizational chart of responsibilities. The panel notes that the NCNR is moving in this direction by utilizing the internal NIST Safety Evaluation Committee for reviews of changes in reactor operations.

• The center has made great strides in the development of instruments and expertise in the application of neutron science to problems in biology. The panel believes that this will be an area of growth and that it will need continuous monitoring and funding increases. Consideration should be given to making biological sciences an additional team in the Condensed Matter Science Group.

• The progress made this year to address the need for the involvement of theorists in neutron science is commendable and should be continued and expanded. The center should continue to develop broader connections with other theory groups on the NIST campus and at nearby universities.

• Current NCNR management has been notably successful at developing and protecting an environment of individual scientific excellence along with fostering external collaborations. The NCNR publication record, the number of users, and the peer recognition are metrics that attest to the quality of the individual researchers, the value of the instrumentation, and the research environment.

• Although the NCNR organization is very well managed, the panel recommends that a more formal planning process involving the scientific and technical staff be developed and published.

• The single largest issue facing the center is continuity of leadership. The role of the NCNR director is uniquely important in the national neutron scattering community, especially as interfacility collaborations continue. The director will naturally represent the center, as well as the Department of Commerce, in a variety of national and international forums. The director also carries unique responsibilities for safety and accountability to the U.S. Nuclear Regulatory Commission with regard to licensing and operating the neutron source and has exceptional staff and budget responsibilities. These job dimensions should be recognized as fundamental to the NCNR director position and should be seriously considered in any leadership transition.

Technical Merit

The mission of NCNR is (1) to operate the NIST Research Reactor cost-effectively while assuring the safety of the staff and general public, (2) to develop new methods and applications for neutron measurements, and (3) to apply these methods and applications to problems of national interest. The NCNR is responsible for operating its research facilities as a national facility serving researchers from industry, universities, and government.

The panel continues to be impressed with the high quality of the NCNR's scientific programs and its safe and effective management of the reactor. The instruments available to the neutron research community that uses the NCNR are among the best in the world, and the research occurring on these instruments is influential in a number of scientific fields. The NCNR is a facility of substantial national importance. According to a survey performed by the Institut Laue-Langevin in 1999 through 2002, the NCNR has ranked second worldwide among neutron science facilities in the number of papers published in high-impact scientific journals such as *Science, Nature, Physical Review Letters,* and the *Journal of Molecular Biology*. This opinion is reinforced by the June 2002 report of the federal-government-wide Interagency Working Group on Neutron Scattering (organized by the Office of Science and Technology Policy), which finds that "the NIST facility is the only U.S. neutron science facility that currently provides a broad range of world-class capability."

Now and in the immediate future, the NCNR will be the principal site at which to do neutron research in this country, as the reactor at the Brookhaven National Laboratory has been shut down, and it will be approximately 4 years before the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory comes online and another 2 years after that before it is fully ready to serve the broader research community. However, the staff at the NCNR continues to actively plan for complementing SNS and its capabilities when it becomes operational. Decisions about what new instruments to develop and whether to refurbish or replace various older instruments are being made in the context of the capabilities that will be available at SNS and the types of experiments that are better suited to the NCNR's steady neutron source. This effort is fully consistent with the recommendations of the Interagency Working Group on Neutron Scattering.

Decisions about facility improvement at the center also take into account external input from a number of sources, including the NCNR Users Group and its Program Advisory Committee, this panel's annual assessment, and the 1999 NRC report on managing the nation's multidisciplinary user facilities.[2] The NCNR staff's awareness of the overall context in which neutron research occurs and of the constant evolution of the field is exemplary. Continual improvement of the NCNR facility is critical, as a user community for SNS will exist only because of those users' experience with and access to existing neutron research centers, of which the NCNR is the largest and most effective in the United States. In fact, many of SNS's users will have been drawn into neutron science by results obtained at the NCNR and will have been trained at this facility.

The NCNR is divided into three groups: Neutron Condensed Matter Science, Reactor Operations and Engineering, and Research Facilities Operations.

The Neutron Condensed Matter Science Group has the prime responsibility for the second part of the NCNR's mission and provides scientific leadership for the third part. The group carries out a program of research relevant MSEL and NIST programmatic needs, develops the scientific basis for

[2]National Research Council, *Cooperative Stewardship: Managing the Nation's Multidisciplinary User Facilities for Research with Synchrotron Radiation, Neutrons, and High Magnetic Fields*, National Academy Press, Washington, D.C., 1999.

instrumentation, develops new applications of neutron methods to service a broad range of problems, and provides scientific leadership for the instruments in the user facility.

The Neutron Condensed Matter Science Group is divided into five teams, each of which both performs research and supports the instruments used to do the research. This support includes improving existing instruments, developing new instruments, and facilitating the effective use of the instruments by the NCNR's national user community. This group is also home to the National Science Foundation's (NSF's) Center for High Resolution Neutron Scattering (CHRNS), which provides users with access to a range of neutron scattering instruments. The NCNR is developing a research effort in the life sciences, which is now supported in part by recent funding from the National Institutes of Health, to form the Cold Neutrons for Biology and Technology (CNBT) collaboration. The work of these groups is discussed in the subsections that follow.

The Reactor Operations and Engineering Group has the prime responsibility for the first part of the mission. It handles the day-to-day operation of the reactor, the planning and execution of upgrades and maintenance, and regulatory compliance. In addition to these ongoing duties, at the present time this group is heavily engaged in preparing an application to relicense the reactor for an additional 20 years, through 2024.

The Research Facilities Operations Group, together with the Reactor Operations and Engineering Group, ensures the safe and effective functioning of the reactor and the efficient production of neutrons for research. The work of these groups is discussed below, in the subsection entitled "Research Facilities and Reactor Operations."

Overall, NCNR scientists' strong, collaborative relationships with users of the facilities' instruments maximize not only the efficiency and effectiveness of the work done but also the quality of the results produced at the NCNR.

In the following subsections selected projects that highlight the technical quality and merit of the work at the center are discussed, by group.

Neutron Condensed Matter Science

Scientists in the Neutron Condensed Matter Science Group are pursuing a variety of research topics uniquely suited to investigation by using the properties of neutron spectrometry, scattering, reflectometry, and diffraction. These topics range from understanding polaron dynamics, twisted magnetic structures, charge-orbital-driven transitions, and hydrated clathrates to measuring and modeling manufacturing-induced stress distortions in metals. The topics presented to the panel were impressive in their depth, in the quality of the experiments, and, perhaps most importantly, because the kinds of questions and experiments being pursued foster the development of new interpretations, new questions, and new instrumentation.

Particularly notable is the excellent research program concentrated in the area of strongly correlated materials. This program emphasizes oxide materials, including polaronic properties of colossal magnetoresistance manganites and relaxor ferroelectrics and magnetic properties of n-doped cuprate superconductors. The experiments conducted on frustrated magnetic systems and the reflectometry studies of buried magnetic twists are leading edge. The small effort in measuring and modeling manufacturing-induced stress distortions in metals continues to fill an important niche for industry by putting current empirical finite-element methods on a more robust, scientific basis.

Development of the state-of-the-art triple-axis spectrometer is on schedule and will be an important addition to the instrumental capability at the NCNR. The Neutron Condensed Matter Group has excellent postdoctoral fellows and maintains a very strong outside collaborative network of users.

Access to appropriate levels of expertise in theory and modeling as related to the experimental program at the NCNR has been an ongoing concern of this panel. The NCNR leadership has taken this observation very seriously and, within the confines of the various constraints (budgetary, space, and so on), has responded very positively. A modest group now exists that includes two permanent team members and several long-term postdoctoral researchers, together with several short-term visitors, some of whom are quite senior. Current activities center on first-principle simulations of lattice vibrations, numerical studies of Hubbard models as applied to the magnetic oxides, and studies related to neutron scattering instrumentation. These investigations are world-class science that couple nicely with other research activities of the NCNR. The panel would especially like to underscore the recent elegant application of hidden symmetries in the orbitally degenerate Hubbard Hamiltonian, as applied to the metal oxides, which enormously enhances the capabilities of numerical simulations of spin/orbital ordering.

Center for High Resolution Neutron Scattering

A major facilitator of access to the NCNR instruments by external users is the NSF, which supplements NIST support for the Center for High Resolution Neutron Scattering at the NCNR. CHRNS consists of six instruments: the 30-m small-angle neutron scattering (SANS) instrument at NG-3 (neutron guide 3), the ultrasmall-angle neutron scattering (USANS) instrument, the spin-polarized triple-axis spectrometer (SPINS), a time-of-flight disk-chopper spectrometer (DCS), a high-flux backscattering spectrometer (HFBS), and a neutron spin echo (NSE) spectrometer. The SANS instrument was constructed using NSF funds, and CHRNS pays 100 percent of its operating costs. CHRNS and the NCNR each contributed 50 percent of the construction costs for SPINS and the USANS, and they share the operating costs equally. DCS, HFBS, and NSE were added to the CHRNS umbrella in 2001, and NSF's support of 60 percent of the operating costs for these inelastic scattering instruments has allowed the NCNR to expand the amount of user time available on them. Greater than twofold increases in neutron flux are provided by the advanced cold source, placed into operation in March 2002, for the longer-wavelength (cold) neutrons of importance for these instruments. The CHRNS-supported instruments are among those most in demand. For example, requests for usage of DCS was 3 times greater than the time available in the December 2001 proposal round and 2.5 times greater in the September 2002 round. The six CHRNS instruments hosted 440 users in 2002, including 118 graduate students.

The CHRNS instruments collectively cover seven orders of magnitude in time and length scales of 0.2 to 2000 nm (five orders of magnitude), including the regions of importance for nanoscale and mesoscale science. The instruments enable scientific studies of high impact on the structure and dynamics of many different materials of fundamental and technological importance. SANS alone attracts about 180 users per year; they work primarily in complex fluids and gels, polymers, structural biology, and magnetic and superconducting materials. HFBS, DSC, and NSE are each the only instruments of their respective type in the United States. Because of new ideas in tuning resolution and intensity, DCS is an extremely flexible instrument covering a wide range of science. It is currently the best instrument of its kind in the world. Recent studies on DCS include dynamics of proteins encapsulated in gels, vibrational densities of states in glassy materials, diffusion of hydrogen in single-walled nanotubes, and water dynamics in mesoporous solids.

CHRNS has recently decided to focus the funding that it has available from NSF and the NCNR for upgrades on two rather than three instruments, namely, SPINS and a 10-m SANS. These upgrades continue its exemplary record of improvements in instrument capabilities. The timetable for the sub-millisecond time-resolved SANS project will be extended, with a near-term focus on expanding its science case. This is a commendable example of the NCNR's philosophy of adequately funding the highest-priority projects rather than spreading resources across all projects.

CHRNS has a strong record of education and outreach activities that are favorably impacting the next generation of U.S. neutron scatterers. CHRNS funds undergraduate students who work at the NCNR as part of NIST's Summer Undergraduate Fellowship Program. CHRNS's summer schools attract more than 30 participants annually, of whom more than 30 percent are women or members of underrepresented groups. In 2002, 21 Ph.D. degrees were awarded that were based in part on work done at CHRNS instruments, with five of those going to women and one to a member of an underrepresented group.

Life Sciences and the Cold Neutrons for Biology and Technology Collaboration

In 2001, the NCNR joined with five universities (the University of California at Irvine, Rice University, the University of Pennsylvania, Duke University, and Carnegie Mellon University) to form the Cold Neutrons for Biology and Technology (CNBT) collaboration. This group received funding from the NIH, an impressive "first" in NIH involvement. The funding has been used to support a variety of initiatives: a new diffractometer/reflectometer for biological structure determination, time on the 30-m SANS instrument, staff members and postdoctoral research fellows (hired by the universities and placed at NIST), as well as new computer-modeling and laboratory capabilities. This support is particularly timely given the growth in the numbers of published papers describing neutron scattering by biological macromolecules and by complex fluids.

The NCNR has made splendid use of the new NIH resources. Active collaboration on RNA is occurring with groups at Johns Hopkins University and the University of Maryland. Several new lines of research are now under way in computer modeling, structure determination, and molecular dynamics. Summer schools on neutron scattering should be particularly attractive to those studying biomolecules.

The NCNR is working to show biologists and biophysicists by specific example the value of neutron scattering to an understanding of the workings of biological macromolecules. Projects that illustrate the power of neutron scattering include ribozyme folding under the influence of added counterions, comparisons of hydration and structure of bound versus free proteins, and characterization of protein/DNA assemblies. For example, single proteins, observed free and encapsulated in porous materials, reveal differences in internal motions as well as the expected differences in rotation and translation. Diffusion of water confined in approximately nanometer-diameter pores will likely reveal properties of water on protein surfaces, in protein cavities, and especially in transmembrane ionic channels. The timeliness and impact of the results from these projects could be improved with the addition of another person doing molecular dynamic simulations to help interpret the scattering data and with the addition of another experimentalist on SANS.

Research Facilities and Reactor Operations

The Research Facilities Operations Group has the role of managing shared resources in support of the neutron science program at the NCNR. The activities of the group include beam-line operations; instrument maintenance, development, and upgrades; facility operations; and software support. This group consists of 40 staff members, including scientists, engineers, and technicians, of which 33 are NIST employees. This staffing level allows the NCNR to maintain effective support for instruments at approximately 4.5 support staff per instrument, which is essential for the efficient running of the facility.

The group is well organized and efficient; morale among the staff is high. In an environment in which the workload is demanding and varied, clear priorities have been set and communicated to the teams. The panel fully endorses the decision to give highest priority to maintenance and support for running instruments, to be followed by support for instruments under development.

The Research Facilities Operations Group has 10 major development projects under way, including new instruments and upgrades to both instruments and support systems, all of which are progressing well. Understanding that robust instrument development is essential for the continued health of the facility, the NCNR maintains a target of completing 1.5 to 2 new instruments or major instrument upgrades per year. In addition to maintaining operating instruments, this goal will create a severe load on the staff of the group—it is well recognized that an engineering group of 12 staff would be required to maintain this development plan. Current instrument development obligations will consume all NCNR engineering resources for the next 5 years.

This group is following commendable paths to optimize the use of resources, including the following: increased emphasis on standardized components and approaches, increased use of external engineering and manufacturing, a move toward team-based design efforts, and the installation of automated facility monitoring systems. The management and staff of the group understand that these efforts should be expanded to ensure that resource sharing and communication are achieved across all U.S. neutron (and X-ray) facilities to prevent any duplication of effort. Despite these moves toward increased efficiency, it is clear that without increased support, the group cannot sustain the level of support required for the operation of instruments. An appropriate (however lamentable) solution would be to remove selected instruments from the user program as new instruments come online in order to maintain the crucial level of 4.5 support staff per instrument. The $6 million neutron science initiative in NIST's FY 2003 Presidential Budget is critical to maintaining the growth of the NCNR as a major user facility.

The NCNR management recognizes that setting priorities for new instruments and upgrades requires a clearly defined process involving input from in-house scientists and the user community while maintaining an overview of the broader U.S. neutron scattering context, including the new opportunities that will be available at the SNS in the future.

The NCNR management is participating actively in regular meetings of the U.S. neutron facility managers, as recommended by the Interagency Working Group on Neutron Scattering, in order to address issues of resource sharing and coordination of facility development.

The panel was impressed by the highly successful design, installation, and operation of the new cold neutron source. The performance easily meets the predictions, with an increase of more than a factor of two in flux at long wavelengths. The achieved reliability of 99.95 percent is truly impressive and is the direct result of the careful design of a passive control system and modification of the compressors. The panel commends the NCNR management for its foresight in building two cold neutron source inserts in parallel, one of which will serve as a spare, hence ensuring reliable operation of the facility with reduced incremental cost.

Additional successful improvements, which have significantly enhanced the performance of the instruments, include replacement of the crystal filter for the SANS instrument with a new optical filter providing a significant increase in flux at long wavelengths, and a rebuilding of the channeled guide for the DCS spectrometer that has led to improved performance at high energy resolution. Installation of a new optical filter for guide NG-7 is pending a suitable shutdown opportunity.

The Research Facilities Operations Group has an important role to play in the success of the NCNR as a user-based neutron facility, and it is achieving this role efficiently and reliably. A transparent organization has been set in place with clear priorities and goals. Management of the group requires an unusual combination of engineering capability, scientific knowledge, and understanding of the needs of the user community. The Research Facilities Operations team recognizes the importance of maintaining this expertise as the facility develops.

The Data Analysis and Visualization Environment (DAVE) project was initiated in November 2001 in response to a clear need for a user-friendly, coherent data reduction, visualization, and analysis software. The progress made by the eight-member development team, which combines the expertise of instrument scientists and computer scientists, is impressive. Since the public release of the DAVE software in December 2002, it has been employed by users of NCNR spectrometers and members of the neutron scattering community analyzing data obtained on neutron spectrometers all over the world.

The DAVE development team recognizes the importance of incorporating standardization among software packages developed at different facilities. Although based on an internal data format, the software will support standard formats such as NEXUS. The future maintenance and development of DAVE will require an allocation of significant resources. The panel commends the efforts of the DAVE team to share the development of the software environment with users outside the NCNR and with other facilities.

The major emphasis of the Reactor Operations and Engineering Group this past year has been on matters related to the anticipated relicensing of the reactor for 20 more years of operation. Considerable care has been taken to identify, examine, and anticipate all of the technical and logistical issues related to both regulatory matters and to reliable operation for future world-class scientific research. All of these activities are progressing on schedule to meet the anticipated submission date of the relicensing application to the Nuclear Regulatory Commission in 2004.

One of the very valuable features of the NCNR reactor is the well-established characterization (energy spectrum, and so on) of the neutron fluxes that it produces in its various possible operating modes. It is very important that great care be taken to avoid any future modifications of the reactor that would result in destabilizing that scientific knowledge base or the capability of the reactor to continue to produce neutron fluxes necessary for cutting-edge research.

Completed in 2002, the new cold neutron source more than doubles the neutron flux in the 15-Å to 20-Å wavelength range with lesser, but still significant, gains at shorter wavelengths.

A new electrical supply for the reactor building was installed, with improved transformers and switchgear. This improvement provides increased capacity for both current and future operating and experimental facility loads.

New cooling towers, required for the extended life of the reactor under relicensing, became operational. The improved design of the towers successfully eliminates the large highly visible water vapor plumes in cold weather, which have aroused repeated statements of public concern.

The reactor uses semaphore-type control rods (shim arms). New shim arms and shim arm assemblies have been fabricated to meet future needs. There is now on hand a shim arm supply of at least 4 years. Shim arms for an additional 28 years are currently being manufactured. Increased reserves of nuclear fuel and heavy water are being developed to assure future reliable and scientifically stable operations in the extended licensing period.

A new digital instrumentation console for reactor operations and safety monitoring is being designed with the assistance of Brookhaven National Laboratory. Care is being taken to ensure that in the new design no important safety features (e.g., “operator friendliness”) are lost. A mock-up will be built near the present control room to allow the reactor operators to consider it and offer their comments.

One new area of regulatory activity that has expanded greatly over the past year is that of physical security. The Nuclear Regulatory Commission has issued a number of directives requiring attention to this issue and significant expenditures. A new vehicle-exclusion area has been constructed, new vehicle barriers have been installed, and further improvements are under way. Additional surveillance equipment has been installed.

The availability of the NIST Research Reactor at power in 2002 has been outstanding, with 153 days of full power, 94 percent of which were operational. Considerable attention continues to be given at all levels to operational safety, radiation protection, and industrial safety. Nuclear Regulatory Commission inspections have emphasized all of these, and the commission's inspection reports have been very favorable. Because of the number of high-radiation-area maintenance tasks, exposure of personnel to radiation was somewhat higher last year than in the past, but levels of exposure are still acceptably low because of the strong NIST commitment to ALARA—exposure as low as reasonably achievable. The industrial safety record is also very good. One minor, lost-time accident occurred last year, but there have been none in previous years.

The Brookhaven National Laboratory has been awarded a contract to perform new safety analyses of the reactor using state-of-the-art calculation methods. For the cases examined to date, the new analyses show that calculations originally performed in licensing the reactor were conservative. This effort will be completed in 2003 and will be submitted to the Nuclear Regulatory Commission in the relicensing Safety Analysis Report.

One issue receiving much attention is the condition of the aluminum reactor vessel resulting from its neutron bombardment and how well it is expected to perform out to the end of the 20-year relicensing period. In-house assessment of this question using data from the Brookhaven research reactor thus far appears to indicate that there is no serious problem. If the final results of the assessment suggest the need for additional data to support the Safety Analysis Report, samples can be taken from a rabbit tube in the reactor vessel.

Another problem area is the thermal column cooling system tank, which began leaking heavy water. Close examination of the tank showed that the leaks were at welds, which could not be repaired in place. To deal with this problem, several actions have been taken. The heavy water supply for the thermal column cooling system has been isolated from the reactor heavy water primary cooling system, and the thermal column now has its own heavy water supply. Any leakage is collected and saved. Reducing the flow of cooling heavy water to the thermal column has caused the leaks to self-heal, so currently there are no detectable leaks. To ensure that a replacement tank is available on short notice if the leaks resume and increase, a completely new tank has been fabricated and will be delivered very soon for installation, if needed. In the meantime, if necessary, the heavy water could be replaced by ordinary water and the reactor could continue to operate, but without the thermal column.

A more troublesome problem is the leakage occurring in the copper tubes carrying the cooling (light) water in the biological shield. The precise cause of this leakage has not been determined because of the inaccessibility of the tubes, which are embedded in cast-in-place lead and concrete. Various devices are being used and/or developed to examine the tube walls' interior surfaces, but the small size of the tubes and right-angle bends have made it very difficult to introduce surveillance instruments at the locations of leakage. Work on this problem is ongoing. Currently the leaking tubes are resealed with a propriety solution applied during shutdowns. Pressure indicators on all of the individual tubes are regularly monitored manually from the C-100 catwalk installed to provide safe access to the containment ring header. A contractor using a test rig onsite is developing what might be a better method of sealing the leaks by pumping a different proprietary mixture into the tubes. If this is not successful, the problem may continue to be treated by sealing the leaking tubes with the current procedure, a process that has worked for 15 years. The problem is more of a nuisance than a threat.

Program Relevance and Effectiveness

The primary customer of the NCNR is the neutron science community of researchers who use the reactor and associated instruments at NIST to perform fundamental and applied research in a wide variety of fields. The panel commends the NCNR staff for its continued focus on effectively serving these users. The NCNR provided the basis for more than 318 papers accepted or published in archival journals in FY 2002 and for 79 invited talks by NCNR staff. The NCNR hosted a summer school in FY 2001 on structural studies with SANS and reflectivity, which was attended by 40 people, mostly graduate and postdoctoral students.

The NIST neutron facility has been a leader in serving industrial needs at neutron sources. During the past year, the facility served a total of 1,776 participants, including researchers from 47 different industrial organizations and 127 (U.S.) universities, many of whom are working on industrial projects.

Many different models are used to support the users of the NCNR. Some people are part of research collaborations with NCNR scientists, who do the experiments on NCNR instruments. In other cases, external scientists apply for beam time on the instruments to do their own research projects. A past concern has been the quality of the data-gathering and analysis tools available to users, and the neutron science and Research Facilities Operations personnel have devoted a significant effort to improving the situation. New tools now available to users include the DAVE software for treating and analyzing time-of-flight, backscattering, and triple-axis data sets. In addition, the data reduction and analysis software (IGOR) for SANS and USANS data is widely and easily applied by users.

The Program Advisory Committee (PAC) allocates beam time on instruments that are available to the general scientific community. This advisory committee is composed of 8 to 10 neutron scientists (not from the NCNR) who meet twice a year to review the proposals submitted for the various user instruments (currently there are 10 such instruments). For all of these instruments, the number of days of beam time requested in proposals has exceeded the number of days available—in several cases by a factor of two or more. However, NCNR staff and the PAC are able to accommodate a good percentage of the proposals by juggling the amount of time given to each research team. When the panel spoke with the chair of the PAC, it was agreed that, while the instruments were fully used and some worthwhile proposals were not getting as much time as they perhaps deserved, overall the proposal pressure was not unbearable. The PAC workload has also been streamlined by a new online proposal evaluation system.

A past concern of the panel, NCNR management, and the PAC itself has been the rising number of proposals that the PAC must review. A few years ago, the PAC began offering users the option of an alternative proposal mechanism. Instead of a proposal for a certain number of days for a certain project within the standard 6-month time period, experienced, heavy users of the facility could submit a program proposal to cover a series of related experiments over a 2-year period. This approach has worked well, and the PAC continues to improve on it. For example, the PAC has examined the productivity of the first round of program grant awardees with respect to the level of output (i.e., publications) and has found that it is excellent.

Previously the panel recommended that the PAC and the NCNR might consider instituting formal terms of service for PAC members (so, for example, the PAC would consist of a team of people serving staggered 3-year terms). This approach has been adopted.

Center Resources

The NCNR continues to produce amazing accomplishments with very little money compared with the budgets of, for example, DOE user facilities. The NCNR is run in a highly cost-effective and efficient manner. A key element of its success despite limited fiscal resources is the effective leveraging of funds. The NCNR's long-term relationship with NSF continues to bear fruit, with an expansion of CHRNS and funding of CNBT.

With the increasing emphasis on soft matter and biomolecular studies in the NCNR, the panel continues to believe that exploring potential partnerships, recruiting new researchers, and/or establishing a visitor program would offer advantages of increased synergy between theory, experiment, and interpretation. The panel applauds current management support of the synergies between theory/modeling and experiment and encourages continuance of this trend.

Staff morale is extraordinarily high at the NCNR. Personnel recognize the unique role they play in maintaining the field of neutron science at a healthy level in the United States, and they are justifiably proud of the quality of the reactor, instruments, and science that together make up this outstanding facility. Staff are appreciative of the collegial and scientifically exciting environment that NCNR management has fostered. With the construction of the SNS under way, recruitment of some of the NCNR staff to this facility has begun, though only a few people have elected to go to the SNS. NCNR management has expressed the view that training both users and (a few) employees for this large new facility is part of the NCNR's responsibility to the neutron community. Yet, NCNR management continues to take a longer-term view of the NCNR's ongoing value to the United States and the U.S. research community by supporting internal facility improvements (redoing laboratory space for biological use, for example) and instrument upgrades appropriate for thermal neutrons, by addressing security needs, and by pursuing relicensing. Since there is little likelihood of increased resources, the panel commends NCNR management for scenario planning that includes evaluating possible vertical cuts in instrumentation support rather than horizontal cuts that would result in more generally ineffectual instrumentation and project support.

Each year, the panel comments that three of the four most senior managers at the NCNR will shortly be or already are eligible for retirement. The NCNR is to be commended for recognizing the situation, for having a succession plan in place, and for preparing to manage the transition. Such a transition, even with training and careful preparation, will not be easy. Changes in management style plus long periods of time with "acting" leaders (given government's slow process for new hires or promotions) have the potential to make the next several years a stressful time for the NCNR. The transition plan and process will deserve close attention by the MSEL and NIST management, and the panel believes that all parties recognize this need. The panel also notes that transitions and change, while potentially sources of tension and stress, can also be times of great opportunity: The next few years will also give the NCNR a chance to consider new focus areas and to move in new directions. Members of the center staff are aware of the coming transitions but somewhat worried that their current insularity may leave them unprepared to deal with future change or that the current collegial atmosphere may degenerate into squabbling over budget and instrument-support resources.

The issues related to succession planning and training are particularly critical in the reactor operations area. The NCNR has enjoyed a long period of very low staff turnover in this area, which has undoubtedly been an important factor in the high reliability and safety of the reactor operation. Recently, however, the number of personnel retiring has increased, and replacements have had to be recruited. Succession planning and searches for qualified candidates should continue to be conducted well in advance of anticipated vacancies. Successfully completing the current search for a nuclear engineer is critical to maintaining the high level of ongoing reactor operations.

The panel commends the proactive stance that NCNR management is taking in upgrading to industrial safety standards. However, there is cause for concern over difficulties in meeting new security requirements with little or no increase in funding and personnel resources to make needed changes to computers and computer security.

The number of reactor-licensed operators at the NCNR has grown to 20, providing a more comfortable staffing level than that of several years ago. Several new operators have been hired and have qualified as senior reactor operators. However, several senior operators are approaching the time when they may choose to give up active employment. The panel believes that the development of a plan to systematically capture the corporate knowledge of all senior employees at the NCNR would have substantial long-term benefits. This may be particularly important in the future, because new operators coming out of the military nuclear service appear to be less broadly trained than operators were in the past. While knowledgeable in matters focused on control room operations, they do not have the general breadth of technical training outside of the control room that is important for successful accomplishment of the NCNR mission.

Responsiveness to Panel's FY 2002 Assessment

The panel believes that the NCNR has been responsive to comments and suggestions provided in past assessment reports. Most of the issues raised in those reports are long term, and the panel looks for annual progress rather than complete resolution. For example, succession planning and the training of future leaders are serious tasks at the NCNR, given the demographics of the current management personnel and of the staff in reactor operations. Each year, the panel observes that work continues on this difficult front, and it is pleased to see that NCNR, MSEL, and NIST management all recognize the importance of this task.

Resources continue to limit the effectiveness and scope of the center. Every effort should be made to protect and enhance the funds available to NCNR.

Other examples of positive changes at the NCNR reflect its responsiveness not only to the panel but also to the facility's user community. Improvements in the data reduction and analysis software available to users, improvements in the support of ancillary instrument equipment, and improvements in the proposal process all responded to concerns expressed by the panel and the users and should, therefore, be commended.

The panel raised issues in the FY 2002 report:[3] two key issues, the center's responses, and the panel's assessment of those responses are given below.

First Sample Issue

- *Panel comments in FY 2002 report:* "The scientific output of the team in crystallography is of high quality, although, due perhaps to the small size of the team and the demands of supporting the BT-1 diffractometer, its scientific projects tend to move forward slowly. The team should develop a new project or research topic that is uniquely suited to being tackled with neutron diffraction." [pp. 203-204]
- *Center's response:* "We believe that our research on zeolites and other oxides is world class, and especially suited to neutron methods. In line with the concerns expressed, we have strengthened our efforts in this area."

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[3]National Research Council, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2002*, National Academies Press, Washington, D.C.

• *Panel's evaluation of center's response:* The panel commends the center's management for addressing this concern. The merging of theory and scattering experiments on clathrate hydrates and the integration of temperature-dependent structural crystallography with studies of electronic transitions in complex oxides are noteworthy as these studies are well-suited to investigation using neutrons. Merging complementary X-ray and neutron structural studies of zeolites and mesoporous materials with molecular and mesoscale modeling should yield important results on difficult materials of notable scientific and industrial interest. The panel notes the efforts within the crystallography team to support future capabilities at SNS by investigating new image plates and detectors and developing new data interpretation algorithms.

Second Sample Issue

• *Panel comment in FY 2002 report:* "The primary task will be the missionary element (a key component of all NCNR programs): reaching out to biologists to demonstrate the relevance and value of neutron techniques to problems of interest to the biological community." [p. 206]

• *Center's response:* "We agree with the concern, and anticipate that the CNBT consortium will be a prime element in this effort. We are pleased to note that a Director has been hired—Dr. Mathias Lösche, a recognized expert in membrane biophysics. Additional efforts will begin when Mathias settles in at NIST in the next few months."

• *Panel's evaluation of center's response:* The center's CNBT consortium will be a prime element in this effort. A consortium director has been hired, as mentioned above, and this will enable progress.

14

Building and Fire Research Laboratory: Division Reviews

MATERIALS AND CONSTRUCTION RESEARCH DIVISION

Technical Merit

Inorganic Materials and Polymeric Materials

The Inorganic Materials and Polymeric Materials Groups have a common goal: the development of test methods and predictive tools for next-generation construction materials such as high-performance concrete, coatings, and sealants. Each group works over size scales from the nanometer to the macroscopic level and seeks out, develops, and uses state-of-the-art analytical and measurement tools. Both groups are well connected in industry and relatively well connected in academia. The Inorganic Materials Group is sophisticated in its use of modeling, databases, and other computer-based tools. The Polymeric Materials Group is highly proactive in developing laboratory automation and accelerated durability testing. Both groups provide technical support for improving standards and selection criteria for the evaluation, selection, and use of their respective materials and, additionally, support the needs of various federal agencies in addressing the construction and infrastructure needs of the nation.

The strength of the materials groups is their work in establishing the fundamental bases of the durability of building materials. Staff members have expertise in the broad range of disciplines comprised by materials science: chemistry, physics, engineering, environmental health and safety, and economics. The umbrella project of the Inorganic Materials Group is its HYPERCON Program relating to high-performance concrete, which recently completed the second year of a 3-year consortium aimed at developing and validating the Virtual Cement and Concrete Testing Laboratory (VCCTL). The

NOTE: Chapter 7, Building and Fire Research Laboratory," which presents the laboratory-level review, includes a chart showing the laboratory's organizational structure (Figure 7.1) and a table indicating its sources of funding (Table 7.1).

program continues to make strides in measuring, understanding, and predicting the performance of high-performance concrete. The Polymeric Materials Group, which focuses on projects concerned primarily with the durability of polymeric coatings and sealants in its Service Life Prediction Program, operates largely through consortia: Coatings Service Life Prediction, Building Joint Service Life, and Polymer Interphases. In addition, a study of the dispersion characteristics and photocatalytic behavior of particulate microscopic and nano-sized metal-oxide materials used as pigments in building materials, launched in late 2001, may lead to a fourth consortium.

The main program and focus of the Inorganic Materials Group continue to be the prediction and optimization of concrete performance. This program, HYPERCON, is aimed at measuring, understanding, and ultimately predicting the performance of Portland cement-based concretes. All major material aspects of concrete are represented in the consortium, including cement, aggregates, admixtures, and ready-mixed concrete. VCCTL's earlier success was based on a strong foundation in computational material science and theoretical work that established the computer models required to build the microstructure and hydrate Portland cement. Its most recent technical accomplishments include the following: (1) a total reorganization and update of the computer programs and graphical front end used to perform the computational material science, (2) an update of the pore solution constituents and their effects on cement hydration, (3) an update of the database to accurately depict the real aggregate shape and size, (4) updated inputs for cement particle-size distribution, (5) an experimental program that has led to a more fundamental understanding of sulfate attack and resulted in the adaptation of VCCTL code for simulating sulfate attack, and (6) a revised computational module for the prediction of elastic moduli of cement paste at early ages, allowing for the input of additional concrete components such as fly ash, slag, silica fume, and limestone.

Efforts to characterize and find easier ways to measure the plastic viscosity of fresh concrete also continue. Significant effort was made this past year in the area of relating plastic concrete viscosity measurements from different types of concrete rheometers, resulting in a new interpretation of data generated previously and published in 2001. This development is a step toward creating a scientifically sound and practical measurement technique of concrete workability.

Work also continues in the area of characterizing the microstructure of cement and concrete through various techniques, including both scanning electron microscopy and optical microscopy, X-ray diffraction analysis, and both wet and dry techniques to measure the particle-size distribution of cement. Analysis and characterization techniques for cement and concrete are important and required as basic input for modeling of the microstructure by VCCTL. They are also necessary as an empirical check to see how well that microstructure was modeled by VCCTL. X-ray diffraction, especially as interpreted by further work with the Rietveld analysis technique, provides a new and direct way to quantify the precise mineral phase composition of cements and clinkers. Results of this work may lead to an X-ray diffraction standard test method and ultimately to modifications in the current cement specifications.

The Service Life Prediction (SLP) Program remains the dominant thrust of the Polymeric Materials Group. Most of the work continues to take place with the support of and under the guidance of consortia. Approximately half of the experimental work of the group revolves around use of the Simulated Photodegradation by High Energy Radiant Exposure (SPHERE) weathering device, which was developed in BFRL over the past few years and is now fully operational, following the design, assembly, and attachment of reliable environmental chambers. The group seeks to show that the chemical and physical mechanisms of degradation occurring in actual outdoor exposure are very much the same as those that occur in the SPHERE. Establishing this similarity is a key aspect of an accelerated durability test.

Research results thus far from the High Radiant Flux Experiment appear to confirm the idea that the law of reciprocity is obeyed for a model acrylic-melamine polymer over a wide range of radiant flux at ambient temperature and humidity. It is essential that future work explore the relations between outdoor performance and laboratory test results, as is planned. The characterization of epoxy coatings has been carried out with a wide range of tools, including gloss measurements to quantify changes in light reflection, confocal microscopy and atomic force microscopy (AFM) to determine surface morphology and roughness, nanoindentation to assess modulus or hardness, UV spectroscopy to assess yellowing, and various electromagnetic spectroscopies (FTIR, UV, and Attenuated Total Reflectance [ATR]-FTIR) to assess details of chemical changes. The Sealant Service Life Prediction Program currently is active in three areas: (1) the design and construction of a device for transferring light from the 6-ft-diameter SPHERE to small spheres in which mechanically loaded samples can be exposed; (2) the development of an understanding of the nonlinear viscoelastic properties of sealants, which can be complex owing to the Mullins, or strain-softening, effect; and (3) the establishment of the test regimen for nine different sealant formulations. The panel commends the continuing effort in the Sealant SLP Program.

The completion of the first phase of the Light Scattering Materials Characterization Facility within the Polymeric Materials Group greatly enhances the group's capability to characterize the bulk and surface morphology of coatings and thin films as well as the microstructure and dispersion of particles in complex fluids. While the first phase of the facility is directed at the study of solid samples, the second phase, expected to be installed in 2003, is aimed at the characterization of liquids and highly scattering solids. This facility is expected to be the focal point in integrating measurement efforts and results of studies from microscopy (AFM, confocal, SEM), neutron scattering, and nanoindentation and mechanical measurements. Because the facility applies a nondestructive technique, it will strengthen the capability of the group in carrying out long-term weathering exposure on materials.

Past work in weathering and environmental exposure has focused on polymeric matrix degradation. The project on Photoreactivity of Titanium Dioxide will study pigment photoreactivity and establish the effect of pigment photoreactivity on polymer matrix degradation. The expertise of the Polymeric Materials Group in UV light sources, UV dosage measurements, and photochemistry is essential. The success of this endeavor could have a broad impact in areas such as coatings, wastewater treatment, air purification, countering of chemical and biological terrorism, solar cells, cancer treatments, and UV protection. This work is ambitious and timely and, like much of the recent work in this group, well planned and considered.

The objective of the project on Chemical Sensor Microscopy for Nanotechnology is to develop and implement techniques for characterizing chemical properties of materials at nanoscale resolution. Research results have demonstrated that chemically functionalized AFM tips can reveal the chemical heterogeneity of materials surfaces at nanoscale spatial resolution and that elevated relative humidity in the tip-sample environment enhances the chemical contrast between the hydrophilic and hydrophobic regions. Materials examined thus far have included thermoset coatings, copolymer coatings, and self-assembled monolayers. Future work will concentrate on the chemical functionalization and use of carbon nanotubes for AFM and the application of these tools to the quantification of hydrophilic-hydrophobic gradients in polymeric materials. Both of these efforts are highly worthwhile for the advancement of coatings as well as adhesives. The ongoing collaboration with researchers in the Materials Science and Engineering Laboratory and the Physics Laboratory on this project is essential.

A multiyear study of the field analysis of lead in paints is nearing the completion of its investigation of the method of ultrasonic extraction paired with anodic stripping voltammetry (UE/ASV). Following three phases of work done with the guidance of academic collaborators in statistics, the encouraging conclusion has been that UE/ASV is reliable for the field-based lead analysis of paint provided that paint specimens are ground to an adequately small particle size.

Structures and Construction Metrology Automation

The individual research programs in the Structures and the Construction Metrology and Automation Groups continue to be of the highest technical quality and at the cutting edge in their respective fields. Additionally, the work of the Structures Group and the project on fire-testing of a floor truss represent examples of good research interaction between programs; such interaction would be beneficial on a wider scale across projects and groups. Most of the programs in the two groups have been built around the expertise of the research personnel; a broader research vision and agenda should also influence the programs, as is the case for the effort directly related to the collapse of the WTC's Twin Towers. The need for a detailed strategic plan for these groups remains.

Presentations on projects in the area of structural performance under extreme loads could be improved by complementing the definition of problems and stated research objectives with clear descriptions of the nature of the work in progress—for example, describing the outputs for the Progressive Collapse Investigation project, describing the results of testing and delineating how the urban environment is recognized in the database-assisted design for tall buildings in the Wind Research project, and identifying the time line for each objective, as well as the project limits, for the Fire Safety Design project (in which the structures and fire testing researchers are working very well together).

The panel had some concerns. The anticipated synergy following the merger of the former Building Materials and Construction Divisions into the new Materials and Construction Research Division is still an opportunity rather than an accomplished fact, and it remains to be seen how the synergy will be reflected in and affected by the operation of the new division.

The division management needs to develop a clear overall strategy regarding the influx of funds and the technical efforts related to the WTC investigation; the strategy needs to inform the division's long-term vision. There needs to be a clear definition of the involvement of the materials side of the division in the WTC investigation specifically and in the homeland security effort generally. The WTC investigation plan has been fleshed out to address four specific objectives, comprising eight multiorganizational projects. However, organizational and work-related plans need to be defined by a detailed structure identifying work breakdown, milestones, and schedules, so that the project can be effectively managed and so that its status can be clearly communicated. Such a large effort merits a dedicated and skilled project management staff, as was pointed out in last year's assessment report.

A large portion of WTC funds is scheduled to be outsourced rather than used to acquire expertise within NIST and to build a sustainable, long-range, structural risk assessment and mitigation program. The panel is concerned that maximum value will not be derived from the WTC investigation and its associated research and development projects—in particular, the progressive collapse study. NIST's technical efforts may be more profitably directed toward the Dissemination and Technical Assistance Program, which should be multihazard-oriented from the outset. Additionally, a more strategic engagement in general structural risk assessment and mitigation under the NHRP umbrella might represent a valuable contribution by NIST to homeland security.

Program Relevance and Effectiveness

The HYPERCON Program of the Inorganic Materials Group continues to generate both interest in and effectiveness for the construction community, as represented by materials suppliers to that industry. The group recently developed VCCTL Version 3.0 for the VCCTL consortium members and placed the older Version 2.0 on the Internet. Over the past year, VCCTL has been accessed on the Internet by about 9,000 users per month, from more than 80 countries. It is clearly seen as a valuable resource in the computational and experimental materials science of concrete and its constituents. The Inorganic Materials Group hosted the 14th ACBM (Center for Advanced Cement-Based Materials)/NIST Computer Modeling Workshop in June 2003, featuring much of its work in cement hydration, cement and concrete rheology, concrete microstructural characterization, concrete mechanical properties, and aggregate characterization and modeling.

The VCCTL consortium members send a strong signal of their support by each providing $40,000 per year to the consortium effort. Over the past year, the number of participants has grown from one to nine. The work under way is strongly aligned with the overall priorities and research focus recently established by the Strategic Development Council of the American Concrete Institute (ACI), the primary technical and educational society dedicated to improving the design, construction, maintenance, and repair of concrete structures. A document published in December 2002 by the Strategic Development Council of ACI, titled *Roadmap 2030: The U.S. Concrete Industry Technology Roadmap*,[1] outlines consensus goals established by the concrete industry's leaders to improve concrete's performance, quality, and competitiveness. The main focus of the HYPERCON Program—prediction and optimization of concrete performance—aligns nicely with the eight major goals of this document. In fact, the HYPERCON Program has two constituent parts that specifically align with four of the *Roadmap 2030* goals. These constituent parts are VCCTL and Building for Environmental and Economic Sustainability (BEES). Components of these programs will aid in reaching the goals of process improvements, product performance, technology transfer, and industry image described in *Roadmap 2030*.

The Inorganic Materials Group's efforts to improve and refine VCCTL through consortium participation appear to be succeeding very well. The consortium membership is composed largely of materials suppliers to the industry, specifically, admixture suppliers, ordinary Portland cement producers, and aggregate suppliers, as well as the National Ready-Mixed Concrete Association. As the VCCTL consortium completes the last of its 3 years, the panel is very interested in seeing the development of a plan to take the tools of VCCTL not only to the 4,000 ready-mix concrete producers of the United States and those of other nations, but also to construction companies and concrete contractors, building designers including engineers and architects, and prospective owners of concrete-intensive structures. While VCCTL has been designed to be used as one large modeling package, some individual components of VCCTL may prove to be of greater use than others to certain entities and should be packaged in such a way that their effective stand-alone use is possible. The plan that the panel recommends should additionally provide a clear means for the application of VCCTL and its components to code and standard development. The panel envisions that the Inorganic Materials Group could interact with the Construction Metrology and Automation Group of the division, BFRL's Office of Applied Economics, and the BFRL Standards and Codes coordinator for the development of the plan that it recommends as well as for its implementation.

Over the past year, a member of the Inorganic Materials Group received the 2002 ASTM Award of Merit for his service to and participation in ASTM committee activities. He was presented with the C09 Award of Appreciation at the June 2002 ASTM meeting, in partial recognition of his role in the development of a new standard for the use of the impact-echo method for measuring the thickness of concrete members.

With its strong consortium support, the Polymeric Materials Group has both firm financial backing and a rich supply of industrial input on what is of most relevance to manufacturers of coatings, sealants,

[1] See the ACI Web site at www.concretesoc.org/.

and other polymeric building materials. A NIST workshop on photocatalytic effect will be held in FY 2003 and could lead to an additional consortium on the basis of industrial input already received.

The SLP Program generated a NIST Competence proposal for FY 2003 in the areas of chemical nanoprobe microscopy, light scattering, and the photocatalytic effect of pigments. While the Polymeric Materials Group enjoys a fair amount of interaction with other NIST laboratories, it is believed that its Competence proposal could serve as a focal point for more BFRL-wide collaborative work and deserves continued attention and encouragement when it is resubmitted.

Three members of the Polymeric Materials Group received the Department of Commerce Bronze Medal this past year for designing, building, testing, and calibrating the SPHERE UV radiation device around which so much of the group's work revolves and the effective use of which places the group at the leading edge of studies in material durability. Group members also received awards for papers presented on the effects of UV exposure, on the mechanical properties and chemistry of vinyl ester matrix resins, and on spectral photolytic effects on an acrylic urethane resin.

A U.S. patent was issued to three staff members for a humidity chamber for a scanning stylus atomic force microscope with cantilever tracking. Another staff member is now an associate editor of the *Journal of Materials in Civil Engineering*, while another has been elected president of the Rheology Section of the Society of Plastics Engineers.

The dissemination of research results is properly accomplished by the Structures and the Construction Metrology and Automation Groups through relevant meetings, conferences, and workshops (many organized by NIST). The quality and relevance of the research are well documented by numerous awards and special recognition received by staff members in these groups for their scientific contributions.

Division Resources

The WTC investigation represents approximately a 30 percent increase in funding for the Structures Group over the next 2 years. Since the staffing level is not projected to grow during this period, the effort will presumably be accomplished by reassignment of staff and a corresponding reduction in their other ongoing research activities. The panel hopes during the next visit to learn how the division will accommodate the WTC funding spike in the out-years and how it will take advantage of any opportunities presented to expand NIST's expertise and relevance.

Current plans indicate that a large portion of WTC funds will be outsourced. However, no analysis was presented to demonstrate that this option will support building a sustainable, long-range structural risk assessment and mitigation program. The Dissemination and Technical Assistance Program, which should emphasize a multihazard orientation, may hold more long-term promise for the division than will the R&D projects associated with the WTC investigation (in particular, the progressive collapse study).

Appropriate opportunities to expand the industry base and the associated extramural funding for the Structures and the Construction Metrology and Automation Groups should be pursued when they arise.

The resources seem to be commensurate with the research programs and activities of the division; a strategic plan extending 5 years into the future would clarify whether there are plans (not currently apparent) to extend its roles and mission.

Research facilities for the Structures and the Construction Metrology and Automation Groups are of good quality and are adequate for the ongoing research programs. The focus on homeland security is limited to the WTC investigation and a planned research effort on the progressive collapse of buildings. The Materials and Construction Research Division has not indicated a clear focus on a longer-term or larger leading role in support of homeland security. As mentioned above, a more strategic engagement in general structural risk assessment and mitigation under the NHRP umbrella would be a valuable contribution by NIST to homeland security. Efforts in this direction were not communicated to the panel.

No information is currently available on the equipment needs of the Inorganic Materials Group, which has added computing capability in the past year. Enumerated equipment needs of the Polymeric Materials Group include a Nanoscope 4 tapping mode attachment for the group's AFM, a contact angle measurement system, and an ultralow-temperature chamber for electron spin resonance.

The National Construction Safety Team Act of 2002 places significant statutory responsibilities on NIST. The panel hopes during next year's visit to learn how NIST is responding organizationally and whether relevant in-house capabilities are adequate.

BUILDING ENVIRONMENT DIVISION

The goal of the Building Environment Division is to optimize total (life-cycle) building performance through innovative design, integration, commissioning, operation, and maintenance for improved reliability, security, safety, and occupant health, while minimizing adverse environmental impacts. The division's research, development, and demonstration work is carried out in two program areas: (1) that of healthy and sustainable buildings, which involves the division's Indoor Air Quality and Ventilation, Thermal Machinery, and Heat Transfer and Alternative Energy Systems Groups; and (2) that of cybernetic building systems, which involves the division's Mechanical Systems and Controls and Computer-Integrated Building Processes Groups. Activities of each group are discussed in the subsections below.

Technical Merit

Indoor Air Quality and Ventilation

The research projects of the Indoor Air Quality and Ventilation Group represent an important component of the effort in healthy and sustainable buildings. The program has emerged from the long-standing research at NIST on building loads and the indoor environment. The current projects are a natural outgrowth of the need to understand the role that airflow in buildings has on energy use and on occupant health and comfort. The projects continue to evolve to meet changing national priorities. A strength of the group is that the projects provide well-integrated coverage of a broad spectrum of phenomena and applications. The group is recognized nationally for its expertise and is working with other government agencies on problems of national interest.

This group has conducted significant basic research on air and contaminant flow in conventional and hybrid ventilation systems and has disseminated this information to the technical community. Members of the group have been leaders in the development of standards and design tools for ventilation and indoor air quality (IAQ). They are applying their skills to the evaluation of the effects that control strategies have on energy use and IAQ in both residential and commercial buildings. In support of homeland security, new efforts that build on their established expertise are being undertaken toward reducing the chemical, biological, and radiological vulnerability of buildings.

A key area is that of airflow and pollutant-flow model development. The group has developed a number of analytical methods that are widely used in the research, development, and design communities. The CONTAMW software is the basis for much of this activity. This program contains a model for the flows of air and contaminants through multizone buildings. Over time, the group has established the validity of the approach through a comprehensive experimental program, and the current activities are to provide further enhancements to the basic model. These enhancements include extensions to cover moisture and IAQ levels in residential buildings with mechanical ventilation; natural and hybrid ventilation systems in commercial buildings, such as those found in Europe; and a validated CONTAMW model for manufactured housing. Research is being conducted into infiltration and ventilation airflows in commercial buildings using combined thermal and airflow analysis. Work is being done on adding new filter and air cleaner models to CONTAMW.

The analytical developments are complemented by experiments. A commercially available manufactured house has been purchased and instrumented to determine contaminant and ventilation levels. Field measurements of volatile organic compound (VOC) rates in an Oberlin College building have been completed and will be used in model development. The new IAQ test facility will be used to experimentally study multiple mechanical ventilation options as well as natural ventilation and infiltration. These experiments provide valuable data for code development and verification.

The basic research of the Indoor Air Quality and Ventilation Group includes database developments that will allow access to IAQ modeling data for export to CONTAMW and that will link EPA VOC and National Research Council of Canada emissions databases. New databases are being developed for the Department of Housing and Urban Development (HUD) on non-VOC source strengths, filter efficiencies, and occupancy schedules. Finally, in response to the immune building program, the group is extending models on air cleaning, filtration, and chemical transport and reaction; building controls; and models for non-well-mixed zones and plumes. The goal is to develop analysis tools and guidance for assessing the vulnerability of buildings to chemical, biological, or radiological (CBR) attacks.

Another major effort is in the development of ventilation and IAQ design tools. To this end, CONTAMW Version 2.0 has been released; it has simple controls, variable indoor temperatures, and nontrace contaminants, and is faster than its predecessor. A goal of the group is to provide tools that facilitate design on the basis of performance methods rather than of prescriptive rules. A design tool that can control contaminants to set points is being developed.

Air-cleaning devices are being used increasingly in buildings, and there is an effort in air-cleaner performance modeling and database development. This work includes efficiency measurements in a single-zone test house; there are plans to extend the tests to multizone buildings. Cooperative work is ongoing with Puracil, a gaseous air-cleaner manufacturer. Models are being evaluated for their ability to predict the impact on IAQ of filtration and air cleaning. A suite of models will be developed to allow prediction of air-cleaner performance. Finally, an immune building toolkit that is based on CONTAMW is being developed to enable the analysis of various protective measures in event of CBR incidents.

These design tool activities of the group encompass a broad range of applications. The tools are under continual development and verification, which enhances their credibility. This is a strong effort in which the group is a national leader.

The increased emphasis on a healthy indoor environment has led to new control strategies based on IAQ rather than on thermal measures. A major activity of the group is that of evaluating the impact of these strategies on energy use. Among the strategies studied for residential buildings are demand-controlled ventilation, the evaluation of mechanical ventilation, and the evaluation of different systems and components, such as forced-air return, whole-house fan, and heat recovery. The impact of vented and nonvented combustion appliances, the VOCs emitted from building materials, and mold is being determined. Strategies for commercial building ventilation, including demand-controlled ventilation, natural and hybrid ventilation, displacement ventilation, and advanced systems that are thermally decoupled from the space conditioning system, are under study. The research into the energy impacts in commercial buildings is using a combined thermal and airflow analysis.

Thermal Machinery

The Thermal Machinery Group has projects in three areas: (1) MEMS for improved vapor compression systems, (2) two-phase heat transfer with refrigerant/lubricant systems, and (3) simulation tools for evaluating and optimizing the performance of vapor compression systems. On the basis of market and technology trends and continuing worldwide governmental emphasis on climate change, the panel agrees with the group's vision of smarter, more reliable, and more efficient air conditioning equipment.

The project on MEMS for improved vapor compression systems (refrigerant expansion valve and compressor vibration meter) would be the first applications of MEMS in the heating, ventilation, air conditioning, and refrigeration (HVAC/R) industry, following the lead of successful applications in the automotive industry. MEMS prototypes are essentially handmade, so patience and time are necessary to develop a workable MEMS. However, MEMS devices can be mass-produced (like computer chips) when their design has been finalized. Both MEMS applications support the industry need for more efficient and reliable vapor compression systems and are consistent with needs identified by the Air Conditioning and Refrigeration Technology Institute's (ARTI's) Strategic Planning Initiative in 2001 (see the ARTI Web Site at www.arti-21cr.org/21crstra).

The Thermal Machinery Group's project on two-phase heat transfer with refrigerant/lubricant systems is focused on using fluorescence techniques to measure lubricant concentration at the boiling surface for R134a/lubricant systems in pool and flow boiling. The fluorescence technique is superior to the current state of the art and will provide the first quantitative measure linking refrigerant boiling performance to lubricant physical properties. With this information, work can begin on a model to predict the effects of lubricant viscosity, miscibility, and mass fraction on the R134a/lubricant system. The Department of Energy is a cosponsor of this project, as system energy efficiency can be optimized with such a computer model.

The group has three tasks under the project on simulation tools for evaluating and optimizing the performance of vapor compression systems: (1) heat exchangers and heat pump simulation models, (2) genetic algorithms for optimized heat exchanger design, and (3) NIST Standard Reference Data (SRD) simulation programs. Accomplishments during 2002 include the completion of a project cosponsored by ARTI and DOE, which involved laboratory testing and modeling of refrigerant blends operating near and above the refrigerant critical point. As part of the project, a simulation package was completed for the design of evaporators and condensers. This model is now on BFRL's Web site for free downloading. There were 115 model downloads during the first 2 weeks (February 7-21, 2003) of the model's availability. Two successful SRD simulation programs, CYCLE_D (vapor compression cycle performance) and REFLEAK (composition changes during leakage of refrigerant mixtures), were developed earlier by the group and were upgraded in 2002 with a new release of the refrigerant physical properties database REFPROP7. Information on refrigerant system line sizing was also added to CYCLE_D, on the basis of industry recommendations. Simulation tools were on the list of priority projects identified by the ARTI Strategic Planning Initiative in 2001 for the U.S. HVAC/R industry, and these programs are consistent with the ARTI priorities. DOE and SRD funding will continue for simulation tools research in 2003.

Heat Transfer and Alternative Energy Systems

The goal of the projects undertaken by the Heat Transfer and Alternative Energy Systems Group is to provide standards, rating methods, and basic measurements that support the needs of the building community. The group's specific areas of research are thermal properties, photovoltaic power, fuel cells, and moisture in materials. The first two areas are well established; the latter two are in their initial stages.

The thermal property work is a continuation of 90 years of NIST research into thermal property measurements, culminating in a database of thermal conductivity measurements. Part of this project's work is to maintain and continuously improve the database. Recently, the more than 2,000 NIST conductivity measurements taken in previous years have been added to the database. The construction of a thermal conductivity device that would allow measurements to be taken over a 90- to 900-K temperature range is under way. New and innovative insulation systems could then be evaluated. The Thermal Conductivity Measurement project is very solid and is an international resource for thermal conductivity values.

The group's first alternative energy project has the goal of developing measurement techniques, methods of test, rating methodologies, and simulation methods for photovoltaic systems. A test facility has been constructed for measuring the output of photovoltaic panels from different suppliers. The data reduction methodology allows the basic parameters that characterize the cells to be determined. The first set of tests was on four panels from different cell technologies. A second set of panels has been installed, and measurements are being made. Combined with simulation methods, these parameters allow the panel's annual performance to be estimated. Another important output of this research will be the evaluation of predictive models for performance. This is a solid program, providing important baseline data on photovoltaic systems.

The group's second alternative energy project has the goal of developing measurement techniques, rating methodologies, and simulation methods for stationary fuel cells. A test facility is being constructed to allow the testing and evaluation of fuel cells. A residential-sized fuel cell has been obtained and installed. Calibration tests are being planned. Using this facility, the group has the ability to develop test methodologies that can be used to characterize fuel cells so that estimates of annual performance can be made. The proposed testing methodology describes in detail the tests that will be performed and how the basic characteristics will be determined. It appears that this plan is solid and that it will yield results that will become increasingly important as the fuel cell industry develops.

A project on the detection of moisture using ultrawideband radar is under way. The goal is to develop noninvasive techniques for determining the moisture content of materials within the building envelope. Such basic data could be used to validate existing models and provide insight into such problems as mold formation. The work to date is preliminary, and there was little reference to other literature that established the possibilities of the method. It will be important to carefully characterize the capabilities of wideband radar to accurately measure moisture levels and to concentrate on the calibration and sensitivity of the method. The investigators are working with a private firm, and it will be important to build a solid foundation with basic studies before applications to wall assemblies are attempted. The approach has the potential to aid the building industry, but it will need considerable development.

Mechanical Systems and Controls

The programs of the Mechanical Systems and Controls Group provide a window on a NIST organization recognizing industry needs, establishing research projects, working with industry over the years for continuing program relevance, and achieving significant accomplishments. These programs involve buildings communication protocol standards, automated commissioning, fault detection and diagnostics methods, critical infrastructure protection for building computer systems, and a virtual cybernetic building testbed for evaluating the effectiveness of the integrated systems. The starting point for these programs can be traced to the early 1980s, with control algorithms developed for building-energy conservation, dynamic simulation programs, and work with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) on a buildings communication protocol.

The group has led the buildings industry in the development of the Building Automation and Control Network (BACnet®) protocol, which enables the use of and communication between different types of control systems in commercial buildings. The overall objective is practical use of integrated HVAC, lighting, security, energy management, life safety, vertical transport, and emergency response systems. The group is providing technical support for BACnet demonstration projects with the Architect of the Capitol, the State of Iowa (five sites in the Iowa Army National Guard), and the U.S. General Services Administration (GSA). The GSA project is a multibuilding network in 11 federal buildings in the western United States.

The BACnet standard is in various stages of international evaluation and use (in Europe, China, Japan, Korea, Russia), again with group personnel technical support and promotional activities. And, as a highly significant advance, BACnet was recently approved as an international standard (ISO/TC 205), about a year sooner than expected under normal ISO approval procedures. The fast-track approval was a result of a unanimous vote on the submitted standard.

A second important, building-related project of this group involves automated commissioning and fault detection and diagnostics (FDD) of HVAC equipment. Buildings often fail to satisfy performance expectations even at start-up, and failures can go undetected for long periods of time. Building control system complexities may exceed the operators' and users' levels of understanding, leading to inappropriate overrides of the control systems. Automated commissioning and FDD tools are needed to (1) ensure that newly constructed buildings work properly, (2) detect faults as they occur, (3) determine components that are failing or have failed, and (4) recommend maintenance or repair procedures. Examples of possible faults would be stuck or leaking dampers or valves, sensor faults, design faults such as undersized coils, and control logic errors. The group is developing FDD tools and testing the tools using data from test sites of the Iowa Energy Center, Cornell University, and GSA. The FDD tools are being incorporated in control products by Alerton Controls, Automated Logic, and Delta Controls. NIST personnel are providing leadership of U.S. activities related to the new IEA Annex on building commissioning, with particular emphasis on automated commissioning tools.

The project on Critical Infrastructure Protection has the objective of increasing the security of computer systems used for the integrated automation and control of commercial building systems (HVAC, fire detection, life safety, vertical transport, and lighting). The work of the project includes developing secure ways to interconnect multiple buildings, exchange information between building systems and utility providers, and provide information to fire-fighting and law enforcement personnel responding to emergency situations in buildings. The initial phase of this project is to conduct assessments of threats that could prevent or inhibit the operation of critical building systems, including estimates of the probability of occurrence and the potential harm. An important part of the project is the integration of biometric access control systems with the building automation system. Biometric technology could include face, fingerprint, iris, or voice recognition; retina scan; or keystroke dynamics. To get this project off to a fast start, security research contracts have been let to Pennsylvania State and Drexel Universities. This project represents a positive response of BRFL to homeland security program needs.

The projects of the Mechanical Systems and Controls Group are all related, including the Virtual Cybernetic Building Testbed (VCBT), which is a real-time building emulator. The VCBT is a core component that ties together several major research areas in BFRL, including the expansion of BACnet capabilities, the development of FDD tools, the investigation of design and security issues, and the development of a sensor-driven fire model. The VCBT also serves as a vehicle for building cooperation with control companies and for speeding the transfer of NIST-developed technology to the marketplace. The VCBT capabilities are being expanded for testing in the areas of emergency response and other adverse situations.

Computer-Integrated Building Processes

The Computer-Integrated Building Processes Group has taken on a new name (formerly Computer Integrated Construction) to better reflect the broader context within which its numerous projects fit. This new name removes the implication of the group's being interested solely in the construction phase of buildings and emphasizes a focus on addressing *process*-related issues rather than only the final product of building processes. The name change is appropriate, given the variety of issues that the group's projects have addressed, not just in the past year but over the history of the group.

The 2003 research projects under way within the group focus on the development of standard building information models for the architecture, engineering, construction, and facility management (AEC/FM) industry and include work on product data standards for HVAC/R systems and information exchange with first-responders, product data standards for steel construction, and interoperability standards for capital facilities.

Members of the group continue to be active participants both in established organizations and in new groups working on standard building information models for the fragmented AEC/FM industry. As mentioned in last year's report, the group has the appropriate objectivity, the requisite historical knowledge, and the organizational connections to help monitor and promote the variety of activities taking place in this area and to help avoid gross divergences within the evolving standards.

The complex theme that is common across the projects of the Computer-Integrated Building Processes Group is the development, demonstration, and deployment of standard information models that are capable of supporting the decision-making needs of numerous participants in the building process across the life cycle of a facility. This has been a priority theme within the group for many years, and the group continues to successfully develop its variety of projects around this theme. The project on information exchange with first-responders is a positive example of how the new focus on homeland security is being integrated into existing programs. Rather than distracting resources from their long-term objectives, this project effectively broadens the customer base for the services and products that the group has already been working on.

Program Relevance and Effectiveness

The programs undertaken by the Indoor Air Quality and Ventilation Group have long supported the private building sector and more recently the security needs of the nation. There are a number of research projects on commercial building ventilation in cooperation with CEC (the California Energy Commission), ARTI, DOE, and EPA. A CONTAMW-like graphical interface for zone fire models is under development. Group members have been heavily involved with the professional and technical societies that deal with air quality and ventilation. They are represented on appropriate committees of ARTI, ASHRAE, and ASTM, among others. The group leader is the chair of the ASHRAE standard committee on ventilation and air quality (SSPC 62.1) and a member of the ASHRAE presidential study group addressing building safety in extraordinary incidents. Group members are supporting State Department field monitoring and modeling efforts. Their involvement with these agencies and professional societies ensures that the research efforts are focused on the important technical problems of the field. The group has recently undertaken activities in support of homeland security and is involved with working groups of the Department of Homeland Security. The work on developing an immune building toolkit addresses the problems of building safety in extraordinary incidents.

The programs of the Thermal Machinery Group were established on the basis of their vision of future air-conditioning systems, determined from close interaction with industrial, governmental, and academic communities. Examples of this interaction are input from the ARTI Strategic Planning Initiative, DOE financial support, and a workshop held in June 2002 on the refrigerant/lubricant project. The participants in these interactions were very supportive of the research, seeing BFRL as a laboratory with unique capabilities for this fundamental research. The continuing development and support of the SRD programs (CYCLE_D and REFLEAK) are an important service to the worldwide industry, as these programs are cited in many publications. The design model (EVAP-COND) for the heat exchanger represents a new industry tool to assist in system optimization and higher energy efficiency. The group's advances are well documented in industry conference presentations and publications. One paper was given the Award of Excellence for a Technical Paper presented at the 53rd Annual International Appliance Technical Conference in March 2002.

The thermal conductivity measurement work of the Heat Transfer and Alternative Energy Systems Group is recognized internationally as a source of basic measurements. The database posted on the NIST Web site received more than over 800 hits this past year, which is a measure of its relevance. The group coordinated an interlaboratory round-robin evaluation of thermal conductivity measurements from five different international laboratories during the past year. This work is leading to internationally recognized values for thermal conductivity and to the techniques needed to obtain accurate values. The extension of measurements to a broader temperature range is a valuable enhancement that meets the needs of industry.

Photovoltaic electric power has the potential to make a significant contribution to the U.S. energy situation, and the Photovoltaic program would play an important role in achieving this potential. The research undertaken by the group to establish the basic characteristics of this technology would help ensure that installed building systems would perform as desired. The group has published its work extensively and received an ASME Best Paper award for its work on building integrated photovoltaic panels.

The Mechanical Systems and Controls Group has been recognized as an industry leader in its work on BACnet, fault detection and diagnostic tools, and the Virtual Cybernetic Building Testbed. The awarding of funding for the new research on biometric access control systems is an additional indication that the group is recognized as an important contributor to the technology of building communications systems. The group has worked closely with the building industry through workshops at NIST, through industry associations such as ASHRAE, through the BACnet users group, with demonstration projects in commercial buildings, and in many publications and presentations. The *ASHRAE Journal* featured a special 46-page supplement on BACnet in October 2002, with the NIST group leader being prominent as commentary author and coauthor of the lead article, "BACnet® Today." The panel recommends that the group continue with its current approach of extensive involvement with industry groups, companies, and governmental organizations, and that it continue taking advantage of opportunities to present its research findings.

The overall objectives of the Computer-Integrated Building Processes Group are to work with the building industry to establish a sound technical basis for seamlessly sharing information and integrating processes throughout the life of a facility; to transfer the technology to industry through the development of consensus, open standards; to implement and test exemplar software applications incorporating these standards; to demonstrate the integration/interoperability of these and other applications in pilot projects; and to provide validated test-case data sets and test metrics that evaluate the effectiveness of the technology. This is an appropriate set of objectives, all of which must be met, in order for the group's work to achieve the desired influence on the building industry.

These objectives are all achievable to some degree across the projects that are currently under way within the group. The FY 2002 assessment report noted that it was important for the group to move beyond the goal of formal approval of building model standards to one of promoting the adoption of these standards within the marketplace. This change of focus is evident in the project on Data Standards for Steel Construction, in which the group is working with vendors of steel CAD software to help their CIMsteel Integration Standards (CIS/2) implementation efforts and with end-user companies to employ this technology in practice. A move to the implementation and testing of software applications is also evident in the group's work on making CONTAMW Industry Foundation Classes-compliant and in creating a building model of the NIST Administration Building for use in testing.

The accomplishments of the Computer-Integrated Building Processes Group over the past year continue to demonstrate progress toward reaching its objectives. Successful completion of the STEP AP227 and Materials Property Data Markup Language (MatML) standards are examples of technology transfer through open standards. The creation of a test model of the NIST Administration Building is a step toward technology demonstration. The group's publication of three conference and journal papers also helps promote technology transfer.

The panel is pleased to see the move toward formally recognizing the broader scope of supporting the exchange of building information across the complete life cycle of a facility. This move is reflected not only in the name change of the Computer-Integrated Building Processes Group but also in the stated objectives and approaches of 2003 project descriptions. Although primarily symbolic, the group's name change indicates recognition of this broader scope at division, laboratory, and institutional levels, as was recommended in the FY 2002 panel report. This change is tangible evidence of a response to the concern, raised during last year's review meetings, that the staff of the group might be reorganized in a manner that resulted in the loss of attention to the theme of improving building performance through life-cycle information management. The panel is also pleased to see the expanded outreach of group projects and staff to a broader spectrum of industry activities beyond those focused on facility construction, to include design, commissioning, and operations phases of the facility life cycle.

Division Resources

The resources for the Indoor Air Quality and Ventilation Group are appropriate for conducting a broad and well-integrated research effort. This support allows an appropriate balance between the experimental investigations and computer studies. If the group's participation in the homeland security program grows and new research directions emerge, additional resources will be required. The program is a strong national resource, and curtailments in the current activities would compromise its effectiveness.

The Thermal Machinery Group sustained STRS funding cuts during early 2002 owing to the need to redirect budget dollars to other activities. This funding was restored, and the group is working at a more favorable ratio of STRS-to-OA funding (60 percent STRS/40 percent OA). The panel commends the group for completing renovations of five environmental chambers, involving new chillers, new control systems, and removal of methylene chloride coolant. The large "truck" chamber renovation is currently on hold but should be completed in due time, as previous discussions had established the need to maintain the capability of this large environmental chamber. Another commendation for the group is its effective use of visiting scientists and graduate students in project implementation.

The resources for the Heat Transfer and Alternative Energy Systems Group are adequate at present. The group's research programs all involve significant experimental work, and there appear to be sufficient resources in staff and equipment to allow them to carry out the necessary investigations. However, if the energy situation changes so that either photovoltaic power or fuel cells become a more important option, it may be necessary to add staff and other resources to the projects in these areas. The integrated photovoltaic testbed is the only one in the United States, and increased industrial activity could place increased demands for testing and evaluation of new photovoltaic components. The fuel cell industry will undoubtedly grow and mature, and the most promising systems will be identified. There will then be more demand for testing to establish characteristics and standards. The activity in the Thermal Conductivity Measurements project is expected to remain at current levels and not to require increased support.

The Mechanical Systems and Controls Group is effectively using its staff for the wide range of research projects under way. The group had a retirement in December 2002 and is searching for a replacement. With the new funding in critical infrastructure protection, the group has chosen to let contracts to Pennsylvania State and Drexel Universities to assist with this new research.

The Computer-Integrated Building Processes Group added a new computer scientist in August 2002 and is hoping to add another permanent member this year. There are currently no guest researchers to replace the two guests of last year, but discussions with several foreign students are continuing. The group has augmented permanent staff with contract- and grant-supported staff. While these arrangements have resulted in visible progress on group projects, an additional permanent member is still desirable. The issue is one of attracting qualified candidates. The facilities required by the group are primarily computer equipment, and they have been well maintained to meet the needs of the group.

Funding for the Computer-Integrated Building Processes Group's projects is 100 percent NIST funding, with approximately 50 percent coming from outside BFRL. The funding from outside BFRL represents some diversification and healthy interconnectedness beyond the core group and the division. Additional diversification and interconnectedness from funding and collaboration outside NIST could further contribute to achieving group objectives.

FIRE RESEARCH DIVISION

The goals and vision of the Fire Research Division are much better defined than in previous years. The division is successfully pursuing its goal of fire loss reduction by enabling engineered fire safety for people, products, and facilities and by enhancing the effectiveness of firefighters. The division conducts research programs focused on reduced risk of flashover, directed at reducing residential fire deaths, injuries, and property losses; on advanced fire technologies services, working to reduce deaths and burn injuries of firefighters in the line of service; and on advanced measurement and prediction methods.

Programs within the division are well planned and coordinated across its groups—Fire Fighting Technology, Fire Metrology, Analysis and Prediction, Integrated Performance Assessment, and Materials and Products. The group and program managers involve the staff in the planning process. Synergies between complementary talents of the applied and basic research groups within the division were apparent to the panel and appear to validate the merger in 2000. The division now constitutes the preeminent fire research resource in the United States.

The panel reviewed three areas of activity: predictive tools, measurement tools, and the application of such tools for the reduction of fire loss and protection of first responders.

Technical Merit

A core of the Fire Research Division's modeling efforts is the development, application, and distribution of the Fire Dynamics Simulator (FDS). The FDS software incorporates advanced turbulent models (large-eddy simulation), gas radiation, and scientific visualization in an efficient computational scheme that can run on desktop computers. The capabilities of the FDS model have been enhanced in the recently released Version 3.0, which incorporates absorption and scattering by droplet sprays, a multi-grid capability, a mixture fraction combustion model, and gas radiation.

The FDS has been widely used for fire reconstruction, for providing educational tools for firefighters and the public, and for guiding the research program though the design of experiments. Illustrative uses of it are for the examination of the impact on fires of positive versus natural ventilation, for the assessment of the protection afforded by turnout gear under different thermal conditions, and for training on fire-fighting tactics. The FDS and its visualization program, *Smokeview*, have been widely distributed. Validation efforts, including planned tests in the Large Fire Laboratory, are necessary to support confidence in the model's predictive capabilities.

The FDS provides a tool for predicting the gross behavior of fires. Additional modeling efforts in the division are directed at phenomena occurring at smaller scales. These include models on fire spread, predictions of flashover, exposure of firefighters to radiation from fires, and heat transfer through fire-protective clothing and skin. Other modeling efforts include reactive molecular dynamics studies of the thermal decomposition of polymers and of the relationship between polymer structure and flammability.

The division's modeling efforts are complemented by a comprehensive experimental program directed at assessing the effectiveness of fire detection systems, flame-resistant materials, and fire suppression methods. Specialized facilities have been developed to support these efforts. The Fire-Emulator/Detector Evaluator Facility continues to provide an unbiased scientific rating of smoke detectors for industry and the public.

The division has been active in developing advanced, specialized measurement techniques for quantifying the propagation and control of fires. Impressive progress is being made in the development of rapid screening techniques for flame-retardant materials. The division's work includes the development of promising methods—for example, high-throughput flame-spread measurement by use of the gradient compositions, high-output microcalorimeters to obtain the heat release rate, radiant heat flux gradient methods for the determination of ignition, online analytical techniques for characterizing nanocomposites, and UV/VIS spectroscopic NMR techniques for rapidly assessing the dispersion in the polymers of the nanoparticles used as fillers. A new scanning transmission electron microscope will assist with evaluation of the dispersion of the nanoparticles. In support of its efforts on fire spread and suppression, the division is developing and applying methods for quantifying sprinkler sprays and droplet-and-surface interaction, monitoring heat release rates, measuring the yields of principal toxicants before and after flashover, and determining smoke transmittance and the optical properties of soot, fire-induced doorway flows, and the heat flux through firefighters' protective clothing. The Large Fire Laboratory will permit the conduct of experiments with fires of up to 10 MW of thermal output. An oxygen depletion calorimeter has been developed that can measure the time-resolved heat release rate from the fires conducted at these large scales. Experimental efforts support in-house research on the development of fire-resistant materials and validation of models for fire spread and firefighter exposure; they also provide reference methods for industry and other stakeholders.

Progress is being made on the search for improved fire-resistant materials. The preliminary results with clay nanoparticles show a marked decrease in flammability at relatively low loadings, suggesting that nanocomposites with clays or carbon nanotubes might meet objectives of performance, cost, environmental impact, and reduced flammability. Lower-weight protective clothing using heat-dissipative polymers is being evaluated for reducing the fatigue of firefighters. The program for increasing the effectiveness of firefighting strategies is studying the effectiveness of sprinklers, the effect of their placement in different building configurations, the dispersion of the droplets, and the effectiveness on impact of the spray droplets. Fire-spread tools are being applied in areas such as structural collapse predictions, community-scale fire spread, structural ventilation, and improved firefighter safety.

Opportunities exist for the Fire Research Division to radically change the current approach to firefighting by applying advances in sensor and communications technology. A commendable start has been made: the division is participating in efforts to design smart buildings that communicate critical building parameters in real time to first-responders and that monitor firefighter location and vital statistics.

The division is applying measurement and prediction methods to identify the role of fire in the collapse of the World Trade Center's (WTC's) Twin Towers, potential improvements in the design of fire protection structures, and ways to reduce the vulnerability of firefighters and occupants.

The panel is concerned that the staff is currently facing the stressful challenge of providing support to WTC activities in addition to satisfying its traditional customer base. The efforts of staff members are often divided among several (and in some cases too many) projects. These situations should be assessed, and efforts should be made, where possible, to alleviate pressures that can be anticipated in preparing the final report on the WTC investigation. In addition, the division should plan a clear and effective allocation of resources, in both the short and long term, between the WTC efforts and those in support of its traditional customer base.

Program Relevance and Effectiveness

The Fire Research Division is doing an excellent job of targeting its goals and objectives to meet the needs of its stakeholders. Results of division activities are widely distributed to stakeholders. For example, the Fire Fighting Technology Group distributes numerous publications, presentations, and fire-related CDs and videos. The Fire Dynamics Simulator is utilized internationally. The division should consider additional relevant efforts in the areas of monitoring firefighters and in encouraging the residential use of sprinklers. Effectiveness of interaction between the cross-functional teams is improving.

The Materials and Products Group has produced numerous journal articles, conference papers, and reports. The group has worked with its industrial counterparts over the past 4 years to develop a flammability test method for mattresses that reflects real-world bed-fire behavior. The State of California is adopting this test method, effective January 2004. A challenge for the group is to expand outreach to industry.

The Fire Research Division should focus more on codes and standards. The division is currently participating in this area, but a plan should be developed for making more of an impact on the codes and standards process so that codes and standards more fully reflect the outcome of R&D efforts. Additional focus could be generated by the formation of a codes and standards subgroup or by the creation of a division that concentrates primarily on codes and standards.

The National Construction Safety Team Act of 2002 presents another opportunity for the BFRL and the Fire Research Division. Findings from investigations may affect subsequent research and have application to codes and standards. The division needs to define how its resources will be deployed to investigations and how the results of investigations are going to be distributed and applied. The National Environmental Policy Act (NEPA) poses additional challenges for BFRL. In order for the Fire Research

Division to gather data (for validation of models and for other forms of research) at planned fire situations, it must go through an expensive and time-consuming permit process (NEPA). This situation needs to be addressed so that BFRL is allowed to do fieldwork in an expedient manner.

Division Resources

As of January 2003, staffing for the Fire Research Division included 63 full-time permanent positions. There were also 33 nonpermanent or supplemental personnel, such as guest workers, postdoctoral research associates, and resident students.

Divisional resources are at higher levels than in recent years; this has had a positive effect on morale within the laboratory. The OA funding has increased owing to the WTC research effort. The increase in divisional resources has allowed additional permanent staff to be hired. The anticipated loss of significant numbers of senior staff as a result of retirements will create major gaps, and there is a need for a plan to fill the gaps.

The renovated Large Fire Research Facility brought online last year is already overused. The WTC and other projects are fully utilizing the facility, so other ongoing work cannot be performed there.

A specific proposal for a Structural Fire Testing Facility and a strategy for its development and implementation need to be developed this year. This technical thrust area represents a unique opportunity for BFRL to integrate its structural and fire expertise and to create a national research facility and research focus. The facility would provide a much-needed testing capability and would facilitate interaction between several groups within BFRL. It would enable NIST to better support the design of materials and the development of codes that will reduce the risk of fire and diminish the fire damage.

OFFICE OF APPLIED ECONOMICS

Technical Merit

The goal of the Office of Applied Economics (OAE) is to provide the methodology and tools to assess and improve the economic efficiency of systems and processes that ensure the safety and well-being of humans in the built environment. A specialized area in support of this goal is OAE's work in interdisciplinary teams with engineers and scientists from BFRL and elsewhere within NIST to measure the economic impact of new technologies.

The focus of OAE's research and technical assistance is microeconomic analysis. OAE provides such analyses relating to manufacturing, industrial processes, the environment, energy conservation, construction, facility maintenance, law enforcement, and safety. It also develops and conducts prototype training programs in applied economics for scientists and engineers.

OAE's activities identify relevant theoretical advances in applied economics and develop the means to apply them to the design and construction industry. While the researchers do not specifically develop new theoretical concepts, OAE is recognized as a world leader in the application of these theories to the built environment.

OAE is particularly strong in the area of enhanced building performance, and it develops tools to aid decision making in the building and fire safety communities. A core approach is demonstrated in its work with the Department of Energy, whereby the OAE's software-based systems have been established for more than 10 years as the standard in such areas as life-cycle costing and energy efficiency. The analysis and economic simulation systems provide the immediate and long-term costs associated with the selection of different technical systems.

OAE has built on this approach of immediate and long-term economic impact to establish the cost/time tradeoffs for a large number of building and fire systems. The BEES system calculates the embodied energy costs associated with different materials and systems to calculate the relative economic impact. The Bridge Life Cycle Costing (BridgeLCC) system incorporates the durability and expected functional life of materials and systems into the economic cost calculations to aid public agencies in the design of public highways. The Fire Safety Gear Selection system builds on the research results in the Fire Research Division to include performance qualities with related costs to help local fire departments select the most cost-efficient and effective gear. The Decision Support system for HUD's program for advanced technology for housing allows homeowners and builders to select cost-efficient housing systems with respect to durability, maintenance, and repair costs relative to initial costs. These programs are quickly becoming the standard reference for their fields.

OAE collaboration with the other BFRL divisions (Materials and Construction Research, Building Environment, and Fire Research) further leverages the expertise and impact of the BFRL as a whole.

The projects within OAE have clear deliverables and timetables, and they provide direct and recognized value to the building and fire safety community. OAE provides significant value through the economic assessment of other technical developments within BFRL. It also provides a strong point of interaction and integration with the user communities for many projects. For instance, the current project involved in developing a decision tool for the selection of appropriate fire gear is exploring direct contact with the professional associations; this can further link the testing and measurement activities in the Fire Research Laboratory with the firefighter community. Opportunities for further collaboration between OAE and the other divisions should be explored and supported.

The team of researchers in the OAE provide recognized technical leadership in their field through participation in national and international codes and standards organizations. For instance, several OAE staff members are associated with the ASTM Subcommittee on Building Economics, which recently released a new set of standards for building economic analyses. They are also members of industry associations, such as the Construction Industry Institute, the International Design Center for the Environment, and the International Council for Building Innovation. Practiced through long-standing relationships such as that with the Department of Energy, OAE's approach and calculations have become established as the standard in such areas as life-cycle costing and energy efficiency. New relationships—for example, with the Construction Industry Institute for the development of a technology roadmap for the built infrastructure—further enhance OAE's leadership.

OAE is involved in NIST homeland security work. A current project is that of developing a tool for building owners and managers, to aid in the selection of cost-effective strategies for the management of terrorist and environmental risks.

Program Relevance and Effectiveness

The projects in OAE focus on meeting the requirements of the building and fire safety community, particularly through the assessment of the adequacy of economic resources to accomplish their objectives within a set of available choices. A high proportion of projects within OAE is funded from external sources in direct response to the needs of the community. Recently, OAE has increasingly partnered with other BFRL divisions to complement technological developments with economic assessments that can aid the effective adoption and dissemination of these developments throughout the community.

OAE's recent contributions of Web-enabled decision-support tools allow an expanding population of users throughout the United States and internationally to understand and use economic methods to assess different technological alternatives. OAE currently provides Internet access to most of its software programs.

OAE projects are developed and implemented with strong participation from the member communities. For instance, the decision-support tool for assessing alternative building systems and components for housing (PATH-D) was developed using participants from both the homebuilder and homeowner populations. The Internet decision tool for firefighter protective clothing was developed with the U.S. Fire Administration (part of the Federal Emergency Management Agency) as well as the Fire Research Division; BFRL is exploring contacts with local fire departments through the International Association of Fire Chiefs and the International Association of Firefighters.

The impacts of OAE can be measured through the ubiquity of use of its products and services in specific segments of the community. The Building Life Cycle Cost program is the standard reference for calculating the cost-effectiveness of conservation and renewable energy projects for federal, state, and local governments. The BEES software system is fast becoming the standard means through which specific approaches for improving facility sustainability (currently required in most federal agencies by Executive Orders) are selected and justified with respect to life-cycle costs.

OAE disseminates its tools through publications, conferences and meetings, and electronic media. It currently provides Internet access to most of its software programs. Over the past 2 years, there have been almost 75,000 requests to the UNIFORMAT II Internet page and 50,000 requests to the BEES page. The BEES model was downloaded approximately 8,000 times; the Building Life Cycle Cost model, 3,400 times; and the Bridge Life Cycle Costing software, more than 300 times.

OAE provides the core materials for and occasionally is directly involved in specific training programs, such as the Building Life Cycle Cost program. Staff members have also been involved in almost 20 conferences, workshops, and demonstrations over the past year, presenting topics such as the economic incentives for building safer communities and the economic costs of mold in housing. OAE had three major software releases during the past year: BEES 3.0, BLCC 5.1 (for Building Life Cycle Costs), and Autobid 2.0 (for police patrol car selection).

Division Resources

The estimated FY 2003 budget for OAE is $2.5 million, 34 percent of which is STRS funding and 61 percent of which is other agency funding.

As of January 2003, the OAE staff included 11 full-time positions, of which 9 were technical professionals. Recent staff hires have added strength to the team as a whole. The staff appears to be sufficient for current project levels. OAE should explore expanding its use of guest researchers and students, particularly in the areas of sustainability and the cost-effectiveness of new technologies.

The division could also expand its partnering and collaborative relationships with other organizations and institutions that can provide the content for the tools that OAE is developing. For instance, the BEES program strongly leverages the contributions of the U.S. Green Building Council. As the tools and methodologies developed by OAE are applied to an increasing range of areas—for example, the selection of fire protective gear and police vehicles as well as to building security and concrete performance—it will become critically important to involve these user communities in gathering and updating the core content.

OAE has been successful in attracting participation and funding from external agencies (such as the Department of Energy) and in developing new relationships (such as that with the Department of Agriculture). It could also, with additional internal NIST funding and support, further collaborate with the other BFRL divisions and with other NIST laboratories.

CODES AND STANDARDS ACTIVITIES

The staffs of the Materials and Construction Research Division and the Fire Research Division, in concert with qualified and capable subcontractors, are studying the effects of the attacks on the World Trade Center. The investigation includes an analysis of building and fire codes and practices. That analysis should complement, feed, and be fed by an examination of codes and practices by the other teams engaged in the WTC investigation, each of which should be asking, as one of its concerns: “What impact, if any, will our work have on the codes and standards industries of the world, and how can we best disseminate the results of our work in a timely manner?”

The audience for BFRL’s work in all of these areas includes the manufacturers of relevant products and regulators. The building codes currently adopted and enforced in the United States are updated yearly but are formally reprinted on a 3-year cycle. BFRL contributions to the codes should currently target the 2006 edition. Meeting this goal requires that the goal be adopted by a preponderance of BFRL, with the implication that the BFRL divisions consider the codes and standards activities a matter of concern relevant to their particular projects. That recognition is not currently shared across BFRL. BFRL’s Codes and Standards cadre has taken a lead in the ASME A17 discussions of the codes and standards that would govern the potential use of elevators and other mechanical conveyance systems as a means of egress in emergency situations.

The best ways to gain access to and to exit buildings and facilities during emergency situations are still poorly understood by the general public. Through its involvement in the investigation of recent fire tragedies (e.g., the Rhode Island nightclub fire), BFRL can also play a critical role in support of reanalyzing methods of exiting buildings and facilities in emergencies or situations involving perceived emergencies or panic.

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Information Technology Laboratory: Division Reviews

MATHEMATICAL AND COMPUTATIONAL SCIENCES DIVISION

Technical Merit

The goal of the Mathematical and Computational Sciences Division (MCSD) is to provide technical leadership in analytical and computational methods to solve scientific and engineering problems of interest to NIST and to U.S. industry. The technical strength of the division's staff, the breadth of its portfolio of projects, and the technical merit of its individual projects are impressive. These projects include collaborations of varying duration with other NIST scientists, the development of tools and standards in mathematical software and computation, and an imaginative exploration of architectures and algorithms for quantum computation.

The division organizes its work around five technical programs: three general areas (Applied Mathematics, Mathematical Software, and High-Performance Computing and Visualization) and two specific, large projects (Quantum Information and the Digital Library of Mathematical Functions). The four groups of the division—Mathematical Modeling, Mathematical Software, Optimization and Computational Geometry, and Scientific Applications and Visualization—correlate roughly with these technical programs, but many projects cross groups, divisions of the Information Technology Laboratory, and NIST laboratories.

In the previous two review cycles, this panel recommended that the division strengthen its strategic planning, especially since the demand for the division's work outstrips its resources. The division's response to this recommendation has been outstanding: the draft of its triennial strategic plan shows careful attention to the selection of projects and their life cycles and considers internal and external

NOTE: Chapter 7, Information Technology Laboratory," which presents the laboratory-level review, includes a chart showing the laboratory's organizational structure (Figure 8.1) and a table indicating its sources of funding (Table 8.1).

customer needs as well as relevant trends and context in applied mathematics. Division staff at all levels participated in developing the plan, which appears to be guiding the division's activities.

Many of the projects in the Applied Mathematics Program are collaborations between MCSD mathematicians and domain scientists in other parts of NIST. For example, the long-running, collaborative work with MSEL on solidification modeling has yielded significant advances in modeling capability and is recognized as excellent in both the applied mathematics and materials science communities. The Object Oriented Micromagnetic Framework (OOMMF) tool for micromagnetic modeling has had extensive impact both on NIST collaborations with MSEL and EEEL and on external customers. A long-running collaboration with BFRL on construction metrology is achieving good results.

Much of the Mathematical Software Program is currently focused on the Digital Library of Mathematical Functions (DLMF), an ambitious project to produce an online (Internet) replacement for the classic and still-much-used Abramowitz and Stegun *Handbook of Special Functions*. This important project is nearing fruition; the online handbook's release is scheduled for 2004. Successfully managing this extensive project is a significant accomplishment. DLMF continues MCSD's tradition of innovative use of the Internet to support the applied mathematics community. This tradition includes the Guide to Available Mathematical Software, which remains one of the most heavily used NIST Web sites; the Matrix Market, which disseminates standard test data for numerical linear algebra; and the newer Template Numerical Toolkit.

The Mathematical Software Program has also been very active in standards activities, such as the Java Numerics effort. This remains an area in which NIST is able to have a positive effect on a fast-moving commercial standard primarily because of the strong reputation of division scientists in the technical community and because of the Sparse Basic Linear Algebra Subprograms standard, approved in 2003. The Mathematical Software Group has lost personnel in the past few years; the panel hopes that the group will be able to sustain its high level of contribution beyond completion of the DLMF.

The Scientific Applications and Visualization Group joined MCSD about 2 years ago. This group provides a crucial source of expertise for NIST scientists in a wide range of disciplines, from fundamental physics through the modeling of cement and concrete. The latter work includes several projects in collaboration with BFRL and involves a sizable consortium of industrial partners. The reorganization of this group into MCSD seems to be going very well from all points of view and to be viewed positively by the staff involved. The group's opportunities for interaction within the division are, however, made difficult by its physical separation from the rest of MCSD, which is located in NIST North, away from the main NIST campus in Gaithersburg.

The Quantum Information Program, performed in collaboration with NIST physicists and other ITL divisions, is very forward looking research that is necessarily somewhat speculative but has enormous potential importance; NIST is ideally situated to conduct this effort. The quantum bus work in MCSD is a good example: whether or not the specific approach under investigation is successful, this work represents a valuable attempt to identify and grapple with the architectural issues in quantum computing.

MCSD has completed a good draft of a strategic plan and has introduced a new rating system to grade whether projects are in active development. The division has addressed the need to track the life cycle of projects by creating ratings for projects indicating their maintenance levels.

Program Relevance and Effectiveness

The Mathematical and Computational Sciences Division continues to provide high-quality service for its customers, which include other NIST laboratories, industry and academic partners, and the scientific community. Almost all of the projects in the division are highly relevant to customers in one of these categories. Examples include the work on solidification for the Materials Science and Engineering Laboratory, visualization of concrete hardening for the Building and Fire Research Laboratory, OOMMF application to a high-profile physics project at the University of Durham, and support of the thousands of scientists who use mathematical resources on the division's Web site.

The division's Quantum Information Program has considerable scientific relevance. In principle, quantum computers can solve problems much faster than can traditional computers, because the registers of the former can be in multiple superposed states at the same time. Several different physics laboratories have tried to build realizations of quantum computers, with varying degrees of success. The division's research in this area is relevant to this exciting line of scientific inquiry.

Measures of the relevance of MCSD work also include awards received and publications contributed by the division staff during the past year. These include an award for best paper for work in construction management techniques and a NIST Bronze Medal for the OOMMF project. The number of published papers has grown from 12 (last year) to 16.

Although the majority of MCSD projects reviewed seemed to have impressive relevance and effectiveness, the panel was not able to determine whether this is the case across all projects. Therefore, the panel proposes that descriptions of projects should include a discussion of their relevance to customers, to the scientific community, or to high-profile scientific issues.

Division Resources

Resources for the MCSD continue to be flat. The panel was not able to determine whether there is shrinkage, because the delay in passing the 2003 congressional budget is still having a ripple effect on all divisions. There is a personnel shortage in the division, particularly in the Optimization and Computational Geometry and the Mathematical Software Groups. The position filled by the acting leader of the Mathematical Software Group should be filled by a permanently appointed leader.

The situation in the Optimization and Computational Geometry Group is severe because previous personnel losses have not been compensated for. One indication of the problems for this group is that its leader is the division chief, and no plan for changing this arrangement has been presented to the panel. Although there is enough funding to complete the DLMF, funding for its long-term maintenance as well as that for other division Web sites is of concern.

Within externally imposed constraints on personnel, the division chief is doing an excellent job of allocating scarce resources. In particular, the panel sees the hiring of postdoctoral researchers in quantum computing and external authors for the DLMF as good ways to draw benefit from a barely adequate budget. Despite the constraints, morale appears to be high, seeming to reflect focused efforts by the division chief.

MCSD staff members are dissatisfied with the "e-approval" system widely used at NIST. The system apparently has not had the desired effect of facilitating paperwork tasks, and staff consider its Windows operating system incompatible with the Linux used by many division researchers. Staff concerns about the split of division personnel between NIST and NIST North, as well as the larger split between Gaithersburg and Boulder, appear to have diminished.

The panel continues to recommend that NIST management relocate MCSD to the main NIST campus in order to increase the opportunity for building the cross-laboratories collaborations that are its lifeblood.

ADVANCED NETWORKING TECHNOLOGIES DIVISION

Technical Merit

The goal of the Advanced Networking Technologies Division is to provide the communication networking industry with test and measurement research and technology. The division consists of three groups: High Speed Network Technologies, Wireless Communications Technologies, and Internetwork Technologies. The division's work is currently organized in six projects: Networking for Pervasive Computing, Wireless Ad Hoc Networks, Agile Switching Infrastructures, Internet Infrastructure Protection, Internet Telephony, and Quantum Information Networks.

The division focuses on using and developing test and measurement tools, technologies, methods, and metrics to guide and improve the quality of networking specifications and standards and to improve the quality and interoperability of commercial networking products. It also models, simulates, prototypes, and conducts empirical studies to help ensure that specifications for emerging technologies produced by industry and standardization organizations are complete, unambiguous, and precise. The division's work encompasses several of the currently important areas in networking research and standardization.

The work of the Advanced Networking Technologies Division is of consistently high quality and exhibits continuing improvements. The organization of ongoing research around coherent research themes has produced good synergy, fostered communication and collaboration among the research groups, and provided continuity as projects are completed and new activities are initiated. The projects are well focused on achieving specific goals.

Two activities form the core of the division's work on Networking for Pervasive Computing; both activities support the development of networking standards. The first focuses on crafting wireless standards, including IEEE 802.15 Wireless Personal Area Networks and IEEE 802.11 Wireless Local Area Networks, so that they do not conflict within the unlicensed 2.4-GHz radio-frequency band. NIST has taken a leadership role in reconciling relevant standards, and division staff have contributed to a document that recommends practices for designers of relevant standards-compliant communications equipment. Division staff reported that there is increasing industry adoption of designs exploiting the NIST recommendations for synchronized receivers and combined radios. The project has begun to model the performance of dynamic traffic loads at the network layer and has initiated work on ultra-wideband (UWB) communications systems and protocols, exploring interoperability and overlooked interference issues between UWB and existing narrowband communications systems. Division staff are participating in the IEEE 802.15.3a study group on network coexistence. Early entry into UWB coexistence studies is appropriate and well matched to the division's competencies. The timely availability of new technical information will allow the IEEE groups to incorporate the division's solutions into the standards.

The second activity in the area of Networking for Pervasive Computing focuses on the analysis of the resource discovery protocols being developed for ubiquitous computing systems. Division staff are analyzing and simulating protocols to evaluate their functions and how they scale with different network sizes. Current activities include work on modeling the robustness of Jini™ and Universal Plug-and-Play™ in the presence of node failures and developing a simulation model for the Internet Engineering Task Force's standard Service Location Protocol. Division staff have analyzed the performance of service leasing to better understand the trade-off between protocol scalability and service guarantees. The division has responded to the panel's suggestion to extend its investigation beyond proprietary service discovery protocols to include the Service Location Protocol. The Networking for Pervasive

Computing project hosted an industry workshop on pervasive computing for a second consecutive year. Overall, this project is of continuing high quality.

The Wireless Ad Hoc Networks project develops technologies and standards for wireless ad hoc networks (WANETs) and explores video communications in sensor networks. Research activities in ad hoc networks have focused on the development of clustering algorithms and structures and on routing techniques in multihop settings. Division staff members actively participate in the IETF Mobile Ad Hoc Networks working group and have provided valuable results for the ad hoc on-demand distance vector (AODV) routing algorithm to that group and other standards groups. The division is also codeveloping a lightweight AODVjr protocol with external collaborators in the research community. The project team has also continued using and enhancing WANET simulation environments and has contributed to an improved model for IEEE 802.11 local area networks in the popular, commercially available OPNET™ network simulation tool. Research activity in the sensors area has focused on improving the quality of video communications and on developing protocols for self-organizing sensor networks.

The Agile Switching Infrastructures project conducts performance modeling and evaluation of optical networking technologies, focusing on network control, configuration, and management. The division continues to develop and enhance two separate software research tools. The first tool, NIST Switch, provides an emulation platform for multiprotocol label switching (MPLS) optical networks in support of traffic engineering studies. Division staff have successfully used this tool to simulate service quality differentiation between traffic classes transmitted over MPLS networks. Division staff also support and update the GLASS (GMPLS Lightwave Agile Switching Simulator) optical network simulation tool, which promises to be a key research tool for analyzing approaches to network restoration and recovery. In an effort to promote the use of GLASS in the external research community, this past year the project team hosted a workshop for GLASS users. The panel will look for additional evidence of wider external adoption of GLASS in the coming year. The Agile Network project has also initiated a timely and promising activity on the evaluation of optical burst switching techniques.

The Internet Infrastructure Protection project continues its collaborative work with ITL's Computer Security Division on critical network infrastructure protection, including the protection of the Domain Name System with DNS Security (DNSSec). An ongoing activity to evaluate the performance and scalability of the Internet Protocol Security (IPSec) key management protocols has resulted in the creation of a simulation environment for IPsec and Internet Key Exchange (IKE) Versions 1 and 2; development of this simulation framework is now complete. The project's staff participates in relevant IETF working groups; this activity can help IETF participants select a successor to the IKE key management protocol. The staff has made good decisions to investigate secure routing protocols and to shift emphasis from modeling operation of the existing protocols to investigating how protocols will respond to attacks.

As part of the NIST-wide initiative in quantum computing, the Quantum Information Networks project is collaborating with the Computer Security Division on protocols and prototypes for quantum cryptography. The division's principal contribution is in the area of key management protocols for quantum key distribution and focuses on an improved communication channel model and the proper selection of error-correcting codes for that channel. Division staff have devised an alternative reconciliation algorithm to the state-of-the-art Cascade algorithm. The division has also supported the NIST testbed operation by maintaining and upgrading the wavelength division multiplexed transmission equipment and testing the free-space optical transmission link. This project has both a protocol design and a prototyping element using a real quantum channel. Although the practical impact of this work is too far in the future to predict, having a promising, long-term project that complements short-term projects gives good balance to the overall research program. Division staff should remain alert to potential synergies between the Quantum Information Networks project and other projects.

The Internet Telephony project has again made considerable progress with its continuing focus on call signaling protocols. The Session Initiation Protocol (SIP) interoperability test tool is used and valued by the voice-on-IP industrial research community, and the Web-enabled SIP load generation and trace capture elements of this tool are demonstrating their utility in helping implementers debug subtle interoperability problems. The examination of network service programmability through SIP-JAIN (JAVA Advanced Intelligent Network) and the investigation of dynamically scripted SIP agent technology represent a new direction in SIP work. Work also progressed during the past year on the NIST SIP-lite prototype for limited capability devices such as handheld computers. Current research toward XML-based call flow descriptions will help the project expand beyond Java-specific programming environments. The Internet Telephony project continues to be a model for collaboration with industry. The project is also successfully balancing the maintenance of existing software tools with the need to advance its research agenda.

In the coming year, the division has proposed to introduce exploratory projects on first-responder networks, network metrology and measurement, and networking for grid computing. These ambitious initiatives represent promising opportunities for collaborative work with other NIST laboratories, with an associated challenge of developing effective mixes of short- and long-range goals.

Program Relevance and Effectiveness

The staff of the Advanced Networking Technologies Division continues to be active in industry organizations, including the IETF, IEEE, and the International Telecommunication Union. Division personnel are well respected by the staff of these standards organizations and by the communities they serve. The value of the division's standards-related efforts is realized in several ways. Most often, technical work done at NIST, such as modeling and analysis or development of testing tools and evaluation criteria, provides a greater understanding of the implications of proposed standards or supplies solutions to problems that could arise in standards development. The division's familiarity with the networking community and its reputation for an unbiased technical approach are also useful in determining what issues have inspired the standards effort and in defining the technical matters on which the standards bodies should focus. A recent example of such impact is the division's leadership within the IETF's investigations of DNSSec and IPSec, cumulatively leading to the publication of seven IETF requests for comments.

In its previous assessment, the panel continued to discuss industry's practice of developing standards in consortia or other private groupings rather than through the traditional "open" approach that primarily involves professional organizations. There is recent indication that consortia are addressing participation issues affecting NIST, with the Java Specification Participation Agreement cited as a model for other consortia or groupings. The division recognizes that the "closed" system is somewhat antithetical to the NIST and to the governmental philosophy of supporting all U.S. companies and the public in an open manner. However, to support the NIST mission of strengthening the U.S. economy, the division must be able to influence the standards used by the networking community. NIST should continue to communicate its position on this matter to relevant consortia and to define criteria for participation in these consortia.

The Advanced Networking Technologies Division assumes a leadership role in the networking community in part because of its standards-related activities. However, it is important for the staff to expand and maintain its reputation in other ways as well. During the past year, the division staff increased its publications in journals and conference proceedings and attended relevant meetings. These activities are appropriate and responsive to the panel's previous suggestion that the division strengthen its presence in the most prestigious publications and conferences of the networking field. The division should maintain this increasing level of visibility in the community. Division researchers have also participated in professional service activities as technical program committee members, workshop organizers, and journal editors.

Division Resources

As of January 2003, staffing for the Advanced Networking Technologies Division included 25 full-time permanent positions, of which 21 were technical professionals. There were also 10 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers. Two new full-time permanent researchers joined the division staff. Approximately 53 percent of the division's research staff hold doctoral degrees.

The contributions of the division are limited partly by the fact that the number of full-time permanent staff is modest. The division's relevant and effective work is due in part to a large cadre of guest researchers (23 people as of February 2003). This heavy reliance on visitors means that the division depends on temporary employees to support mission-critical projects, and there is the potential for unexpected delays or the premature termination of an important effort when a guest researcher leaves NIST. These risks are currently outweighed by the benefits provided by the added personnel and the relationships built with other institutions, but the division should continue to be careful about maintaining an appropriate balance between permanent and temporary staff.

Division management has noted the absence of a program to hire U.S. citizens as guest researchers at a time when the troubled economy has increased the pool of potential hires. It has also observed that the hiring process for foreign students remains considerably easier than that for U.S. students, and this policy decreases NIST's ability to maintain the closest possible ties to U.S. universities. NIST should revisit its current hiring policies and programs to continue to ensure that it achieves the highest possible level of technical excellence in new hires. Division management expressed some concern over both current and future year budget uncertainties that make it difficult to plan staffing targets. Management also reported that the narrowing spending guidelines associated with external agency funding are further limiting its ability to use those resources as efficiently as in the past.

Morale within the division appears to be good; the staff is enthusiastic about its work and proud of its accomplishments. Prior concerns about the adequacy of the internal information technology infrastructure did not arise. The position of leader for the High Speed Network Technologies Group has been filled, which facilitates the group's stability and focus.

COMPUTER SECURITY DIVISION

Technical Merit

The goal of the Computer Security Division is to improve information systems security by raising awareness of information technology risks, vulnerabilities, and protection requirements; advising agencies of information technology vulnerabilities; devising techniques for the cost-effective security and privacy of sensitive federal systems; developing standards, metrics, tests, and validation programs to promote, measure, and validate security in systems and services; and developing and disseminating guidance for managing secure information technology. The division's programs directly support these goals. The recent emphasis on homeland security has given more impetus and visibility to the division's work.

The programs under way in the Computer Security Division are appropriate and of high technical merit. The division is composed of four groups: Security Technology, Systems and Network Security, Security Management and Guidance, and Security Testing and Metrics.

The Security Technology Group's projects fall into the areas of cryptographic standards and guidelines and of public key infrastructure and applications. Its cryptographic toolkit provides algorithms and techniques to U.S. government agencies and others. The group's modes and key management guidelines (such as SP 800-38B, Recommendation for Block Cipher Modes of Operation) are essential to ensure secure, interoperable crypto implementations in products that are evaluated under the division's Cryptographic Module Validation Program (CMVP) and its National Information Assurance Partnership (NIAP). Work is ongoing in the area of key establishment and management, where FIPS (Federal Information Processing Standards) 140-2 coverage is needed. There is an ongoing discussion about whether work to define block cipher modes should focus on T-DES (the Triple Data Encryption Standard) and AES (the Advanced Encryption Standard) separately or attempt to satisfy the needs of both algorithms with a single mechanism. The progress on AES is critical. NIST should design separate mechanisms, working on T-DES only where there is a clear and ongoing commercial requirement.

The Security Technology Group's e-authentication effort is providing technical guidance on this standard component in government enterprise architecture in the areas of protocols and credentials. This effort has to take into account the September 2003 report of the NRC's Computer Science and Telecommunications Board's Committee on Authentication Technologies and Their Privacy Implications, *Who Goes There? Authentication Through the Lens of Privacy* (National Academies Press, Washington, D.C.) The threat model for the e-authentication effort needs to be clearly and explicitly articulated. The recommendations arising from this effort need to take into account the consequences not only of false positives (accepting an inauthentic individual as authentic) but also of false negatives (rejecting an authentic individual).

The Systems and Network Security Group is working in a broad range of areas, including emerging technologies, reference data and implementations, and security guidance. The group's work on system administration guidance for Windows 2000 Professional establishes a configuration with known security properties that can be used by system administrators, application developers, chief information officers (CIOs), and auditors. This work can influence Microsoft's secure configuration development efforts. The panel supports and commends this effort and the division's cooperation with Microsoft.

The group's IPsec online test facility, developed jointly with the Advanced Networking Technologies Division, is helpful to vendors. It is also a model for the future testing of protocols in that it imposes minimal ongoing costs to NIST and yields good benefits for industry. The group's work on reference data and intrusion detection might be directed toward providing a reference data set for testing intrusion detection systems (IDSs). NIST has often provided reference standards to industry for the calibration of instruments and, in the computer and communications arena, for standards conformance testing. In the field of information security, considerable effort is focused on technology for intrusion detection, yet there are no standard measures for the effectiveness of IDSs. The division should consider the development of a reference data set to support such evaluation for network-based IDSs.

The work of the Security Management and Guidance Group is appropriate and of high technical merit. A primary focus of this work is the Computer Security Resource Center, a valuable Web site that provides information about computer security for the public. The group's NIST SP800-4 (Computer Security Considerations in Federal Procurement) gives government agencies guidance on how to incorporate common-criteria security evaluation language into requests for proposals. The division is working on new language for the Federal Acquisition Regulations that purchasing officers can use verbatim. This is very important and challenging work.

In 2002, the Security Management and Guidance Group published NIST SP 800-30 (Risk Management Guide for Information Technology Systems), which establishes good practice for industry and government and provides guidance to assist federal agencies in performing risk analyses as part of their security procurement and deployment planning.

One of the key programs in the Security Testing and Metrics Group is the CMVP. This program has a quantitative focus and aims to provide automatic measures of compliance. It is an important effort that continues to uncover and correct a large number of flaws in algorithm implementation and documentation. The process certifies cryptographic modules, providing a common assurance definition for customers of those modules. The group validated more than 120 cryptographic modules and more than 150 cryptographic algorithm implementations in FY 2002. This is a high-growth area in which the division resources are stretched to their maximum capacity.

Ongoing work on mutual recognition in CMVP certification has produced seven NIST-accredited CMVP laboratories: four in the United States, two in Canada, and one in the United Kingdom. Accreditation of laboratories outside the United States is important for the economic viability of products undergoing FIPS 140-2 evaluation. The division is also taking FIPS 140-2 to ISO. This will lead to international recognition of a U.S. standard, making companies that have already applied for and received the certification more competitive worldwide. Having a single standard makes the industry more efficient and improves the quality of cryptographic technology in critical infrastructure deployments worldwide.

The National Information Assurance Partnership Program is another important component of the Security Testing and Metrics Group. It focuses on developing common-criteria protection profiles and investigating issues related to the use of these profiles in developing security requirements for the federal government. Fifteen nations have signed mutual testing agreements that recognize the common criteria and the common criteria testing laboratories. The CMVP and NIAP work is relevant to the attempts to provide system architects with better building blocks for constructing secure systems. The division has adopted the panel's suggestion that CMVP and NIAP not be merged.

Program Relevance and Effectiveness

Privacy and security are essential to protecting electronic commerce, critical infrastructure, personal privacy, and private and public assets, and so the work of the Computer Security Division makes important contributions to strengthening the U.S. economy and promoting the public welfare. The division's activities are relevant to a broad audience, including hardware and software makers and users in industry, the federal government, academic and industrial researchers, and the public. The division develops standards and guidelines for cryptography and security implementations, produces tools and metrics for testing compliance and performance of security systems and products, and supports the development of new and more effective security techniques. Division staff members disseminate their results through publications, presentations, advice to government agencies, participation on committees, and Internet posting of tools, databases, and information. The publication record of this group is excellent—it estimates having published approximately 1,400 pages of guidelines within the past 2 years.

Web site statistics suggest how effectively the division disseminates its results. Each month from January 2002 through February 2003, an average of 764,682 pages were returned and 1,281,396 requests were handled. Data from the Computer Security Resource Center Web site is accessed by federal agencies, businesses, and schools.

The Cryptographic Module Validation Program has improved the security and quality of cryptographic products. About 50 percent of the cryptographic modules tested had security flaws, and over 95 percent had documentation errors. About 25 percent of the algorithms submitted for evaluation had security flaws, and over 65 percent had documentation errors. Detecting these problems enables vendors and implementers to correct their products before the modules and algorithms are put into production and bought and used by consumers. This program offers a sterling example of the division's relevance and effectiveness.

Division staff are active in several national and international standards activities and in groups such as ANSI, ISO, and IETF. The committees and activities of these organizations are examples of open standards development and adoption environments. In the case of FIPS 140-2, taking it to ISO will lead to the international recognition of a U.S. standard that makes the industry more efficient. In other cases, it may be most appropriate for NIST to issue standards under its own banner. The division has been relying on the ANSI X9F Committee for the development of random-number-generation standards for key management. However, the X9F Committee is a financial industry committee whose standards might not always be generic and therefore may not always be suitable for promulgation as NIST guidelines.

Division Resources

As of January 2003, staffing for the Computer Security Division included 48 full-time permanent positions and 6 part-time permanent positions. In 2002, $4.7 million of the $15 million division budget was derived from external sources of funding. That ratio (31 percent) indicates a high level of relevance of division programs to its customers.

The division expects that as funding from other sources is identified, 2003 funding will be approximately the same as that for 2002. In 2002 the division chief implemented a successful CMVP cost-recovery program. Charging customers for cryptographic module validation has enabled growth in the number of CMVP certificates issued and improvement in the level of evaluation. This type of effort is needed to ensure that testing for important areas of security continues to be available despite changes in funding from other sources.

There is insufficient funding for pursuing certain important programs. The Cyber Security Research and Development Act of November 2002 created more responsibilities and requirements for the division, but little funding has been appropriated to accompany these authorizations. In addition, many of the programs at ITL (e.g., biometrics, health care, and voting system standards) have major security components. There is risk that the skills in the division may not be effectively leveraged in cross-division initiatives. For example, existing biometrics projects should address security and assurance considerations in collaboration with the Computer Security Division.

The division chief noted that funding for research into security composability under the Cyber Security Research and Development Act has not been reauthorized for FY 2004. The division has ideas but no funding for improvements to the increasingly important NIAP evaluation and certification processes. An additional person is required by the Security Technology Group to conduct work in cryptography and by the Security Testing and Metrics Group to conduct CMVP validations.

Many members of the division staff seem to appreciate that the quality of the facilities in NIST North exceeds that of NIST's main Gaithersburg campus. However, the distance from the main campus introduces difficulties for employees looking for other job opportunities within NIST. Staff have noted that opportunities for change are enabled by the kinds of informal interactions that occur within a facility, particularly for junior members of the team. This situation may be a contributor to the dissatisfaction reported on the employee survey in the areas of opportunities for advancing at NIST, changing career paths at NIST, and fair administration of the job-posting process. In skip-level discussions, staff mentioned that helpful technologies such as instant messaging are precluded by the NIST security configuration; this should be fixed if feasible.

INFORMATION ACCESS DIVISION

Technical Merit

The goal of the Information Access Division (IAD) is to accelerate the development of technologies that allow intuitive and efficient access, manipulation, and exchange of complex information by facilitating the creation of measurement methods and standards. IAD is organized in four groups: Speech, Retrieval, Image, and Visualization and Usability.

The Speech Group is conducting projects in the areas of Rich Transcription, Automatic Meeting Transcription, and Speech and Language Recognition. The Rich Transcription project is designed to support a 5-year research program, Effective, Affordable, Reusable Speech-to-text—the EARS program—sponsored by DARPA. This project is directed toward moving the state of the art from word recognition toward natural-language understanding for large vocabularies. An initial set of benchmarks and evaluations, RT-02, was run in 2002; it required competing systems to extract words from English speech provided by the Linguistic Data Consortium. This speech generally involved several speakers; the metadata extraction task was to partition the speech according to the speaker.

Under the self-initiated Automatic Meeting Transcription project, a meeting room has been fitted with cameras, microphones worn by participants, desk microphones, and microphone arrays mounted near the walls, to provide data on the same meeting from several perspectives. The speech material collected will be turned over to the Linguistic Data Consortium, will form part of the 2003 testbed for EARS, and will be used in the speaker-recognition trials.

The Speech Group is performing several related speech and language recognition tasks involving the processing of audio data or extended data (audio plus imperfect transcription of speech and other derived information). The goal is to improve the quality of software for recognizing the presence of a particular speaker or for determining the speaker's language. Much of this work is supported by the National Security Agency, and annual comparison tests have been held since 1996. In 2002, evaluations were held in which systems were asked to determine whether speech belonged to a given speaker, or whether a given speaker was one of two on a recorded conversation. Comparisons were made for audio-only and extended data; large improvements were seen when the extended data were used. However, gains over the previous year's results were reported to be small, suggesting that new approaches to the technology may be necessary.

The goal of the Retrieval Group's Text Retrieval project is to evaluate and encourage research and technology transfer in new information access technologies. The best-known effort in this area is the Text Retrieval Conference (TREC), which is now in its eleventh year. TREC participation continues to grow; this annual workshop attracts a broad range of government, industrial, and academic participants. TREC provides a forum for leading researchers to evaluate systems by focusing on key common problems. It continues to be a hub for new research, and it helps focus researchers on government challenges (e.g., novelty detection, cross-language retrieval, and question answering). NIST is in a position to serve as an impartial facilitator and evaluator of research in this area. The continual evolution of the program, addressing challenges and pruning topics with diminishing returns, has contributed to its success. In 2002, TREC introduced two new tasks, novelty detection and genomics. The focus on developing solid and reusable test collections and the push to attack new information access problems are the two important contributions of the TREC program.

The Automatic Content Extraction (ACE), Advanced Question and Answering for Intelligence (AQUAINT), Document Understanding Conference (DUC), and Topic Detection and Tracking (TDT) efforts do not have the visibility of TREC because they are smaller, and participation is linked to funding. ACE aims to advance the state of the art in extracting content from newswires, broadcast news, and newspapers. In AQUAINT, the focus is on moving question answering to the full range of complex questions asked by analysts, not just the short, fact-based questions considered in TREC. In DUC, new corpora and evaluation methods are being developed by NIST to evaluate summarization. In TDT, NIST hosted the annual Topic Detection and Tracking Conference and analyzed and presented the evaluation results. Metrics to evaluate new technologies are critical to the success of these government-sponsored programs. The Retrieval Group is developing metrics and collections in challenging new areas such as extraction, summarization, question answering, and interactive systems.

The Image Group's long-standing work and expertise in biometrics are now being sought to address requirements of the USA PATRIOT Act of 2001. This group is running operational and recognition rate tests on very large databases of fingerprint and face images. Test results are eagerly anticipated, because no test of this magnitude and with third-party expertise has ever been performed. Results will be used to make decisions regarding government use of biometrics for visas, border security, and future homeland security tasks. The biometric testing results will also affect a related industry, since a burgeoning group of companies hopes to capitalize on government security contracts. A related biometric activity is that of promoting an interoperability exchange format for fingerprints and palm prints. This work will affect any use of fingerprints or palm prints for public security, because different systems will be used by different adopters. The project on Human Identification at a Distance, which began before the current surge in interest in biometric surveillance, is an example of NIST's anticipation of future important areas.

The Image Group's multimedia work focuses on Motion Pictures Expert Group (MPEG) standards. The project's two staff members promote MPEG-7, chair two related committees, sponsor an MPEG workshop, are designing an interoperability testbed, and promote multimedia standards. The group's Pervasive Computing project has delivered two major items this year: a second version of the Smart Flow system (software complete with an application programming interface, so that anyone can quickly begin researching pervasive computing), and 20 hours of meeting data (at 70 GB per hour) for the Automatic Meeting Transcription project.

The Visualization and Usability Group provides metrics, standards, and test methodologies to improve the usability of interactive systems. A shift in focus is under way from developing visualization techniques and usability testing to evaluation methodologies and standards to support usability and accessibility. This shift in focus is in good alignment with division's strengths, and the group is making good progress in the new direction. Usability is a high-impact area, because poor usability contributes to the high cost of ownership of software and to lowered efficiency. The Industry Usability Reporting (IUSR) effort and the Common Industry Format (CIF) for reporting summative user test results provide the infrastructure for sharing usability information between consumers and producers of software. The CIF standard lays the foundation for factoring usability into software procurement decisions. The Visualization and Usability Group was instrumental in bringing together industry leaders in a series of workshops and in driving the effort at standardization. ANSI approval has been achieved (ANSI/INCITS 354), extensions are being considered, and ISO fast-track procedures are under way. To create benchmark test data for Web usability evaluation methods, the group analyzed the results of pilot studies on CIF testing, evaluation, and reporting. The group is also beginning to explore a framework and methods for evaluating complex interactive systems. Initial explorations in the area of intelligence analysis (AQUAINT and NIMD [Novel Intelligence from Massive Data]) and robotic interaction are focused on important government problems and are receiving financial support from the Advanced Research and Development Activity (ARDA), DARPA, and ARL.

Program Relevance and Effectiveness

DARPA is the sponsor for the rich transcription (EARS) program, and the National Security Agency sponsors the speaker recognition work. The Automatic Meeting Transcription project provides data for each of these, and will provide its data to the Linguistic Data Consortium. There are 17 universities and nonprofit research laboratories involved in the EARS program. The competitions have been open to others, and several U.S. and foreign corporations and schools have participated. The Speaker Recognition project supports and evaluates the work of about 25 organizations, including corporations and several domestic and foreign universities.

The Retrieval Group has a wide range of customers. The intelligence community's ARDA and government agencies such as DARPA work closely with the group to evaluate the success of new information access technologies funded by their programs. In addition, hundreds of participants from government agencies, industry, and academia take part in the annual TREC program. Participation in TREC continues to increase, and it evolves as new tracks are added and old ones are phased out to reflect emerging retrieval challenges.

Customers of work that is related to the Image Group have traditionally included U.S. security agencies, in particular the FBI. The USA PATRIOT Act specified that NIST would be the government arbiter of identification technologies. Homeland security activities also involve DARPA, as well as the Department of Justice and the Department of State for enhanced border and visa security. Much of this work is pertinent to corporations in the security field, such as biometric and smart card vendors.

The Visualization and Usability Group has both government and industry customers. The work on interactive systems evaluation is directly supported by ARDA, DARPA, and ARL, and the voting and health care initiatives will have a usability component. Some of these efforts will result in test collections to support the larger research community. The work on usability reporting has a broader focus on supporting effective information sharing between producers and consumers of software products.

The work performed by the IAD is generally relevant to the customers referred to above. The Rich Transcription project and the speaker recognition work appear to be fulfilling the expectations of their sponsors, DARPA and NASA, respectively. The Retrieval Group works directly with government sponsors of the AQUAINT, TIDES (Translingual Information Detection and Summarization), and DUC efforts to define appropriate evaluation frameworks and metrics. The Retrieval Group's expertise and experience in developing new evaluation frameworks is valued by government agencies and is critical in evaluating the success of new technologies.

The effectiveness of current work related to homeland security cannot be measured yet. However, NIST biometrics contracts have been continued for years, an attestation that the customers believe that the group is producing relevant results. Division researchers have accumulated and tested large fingerprint and face test sets; this work is particularly applicable to border and visa security activities. Test results must be communicated carefully. For example, NIST communication should clearly state the specifications under which border security results apply (e.g., as controlled visa photographs). It is also advisable to emphasize that any attempt to extrapolate the results to different specifications risks creating false security expectations.

External interest in the Pervasive Computing effort appears to have leveled off, judging by the flat attendance at this year's workshop (in contrast to large participant increases for most other IAD-sponsored workshops). Pervasive computing is a speculative research area that NIST management has encouraged, without direct sponsorship, as likely to be important in the future. The panel supports this strategy of entering a promising field early to nurture and influence its growth, and it encourages continued efforts to nurture this field by database creation and by providing infrastructure software rather than by developing component technologies. Application of the Smart Space testbed to real-time, high-throughput sensor data processing for the Chemical Science and Technology Laboratory and the Physics Laboratory at NIST demonstrates the pervasive computing foundation and provides opportunities to learn more about this application.

The work on methods for evaluating complex interactive systems for intelligence analysts and robotic interaction is being defined in collaboration with the sponsoring government agencies. The results of these evaluations will be used directly by the agencies to evaluate technologies developed by contractors and to select and deploy useful and usable systems. The Industry and Usability Reporting work is done in collaboration with industry. There has been strong industry participation in defining and using the CIF standards. The certification by ANSI and the ongoing ISO process suggest that standards will be more widely adopted in the future. The growing recognition of usability as a key component of software procurement is important.

IAD's projects are also generally effective. There are several examples of good dissemination of products and information generated by the division. IAD scientists have contributed more than 50 technical publications and talks. IAD continues to sponsor many workshops, addressing such topics as automatic content extraction, MPEG, rich transcription, speaker recognition, document understanding, INCITS V2, pervasive computing, industry usability reporting, topic detection and tracking, and TREC. For most of these workshops, participation is rising. For instance, in its eleventh year, TREC has had its highest participation level, participation at the speaker recognition workshop has doubled since the previous year, and the Industry Usability Reporting project has a growing, largely corporate, membership currently at 250.

The annual TREC, TDT, and DUC workshops are major forums for interaction among the information retrieval researchers from universities, industry, and the government. The proceedings of these workshops are published by NIST and publicly available on the Web. NIST researchers also publish summative evaluation findings in top information retrieval conferences. The Retrieval Group has led the information retrieval community to explore new directions in question answering, cross-language retrieval, and summarization. TREC continues to provide the research community with rich test collections and assessments of relevance and to work closely with researchers in industry and academia in order to tackle new retrieval challenges in a systematic fashion. TREC has found a balance between the stability needed to explore ideas in depth and to develop useful test collections and the evolution to encompass new directions and technology trends. Several evaluation efforts worldwide, started in the past few years, have been modeled after TREC and include IAD members on their steering committees (e.g., CLEF [Cross-Language Evaluation Forum] for evaluating multilingual issues for European languages, NTCIR [NAGSIS Test Collection for Information Retrieval Systems] for evaluating retrieval issues in Asian languages, and INEX [Initiative for Evaluation of XML Retrieval] for evaluating structured retrieval).

The IUSR effort, driven by the division, has involved a multiyear collaboration with a large number of industry participants. Participation in the fifth IUSR workshop in 2002 had doubled since the previous year, attesting to the growing recognition of the importance of software usability. The workshop helped highlight activities related to the internationalization of CIF and extensions to requirements and hardware, which the Visualization and Usability Group is promoting.

Standards activities are one of the primary means of disseminating IAD work. IAD staff participated this past year in INCITS technical committees on MPEG, biometrics, and IT access interfaces and in Industry Usability Reporting, the Web3D consortium (formed to create open standards for WEB3D [3 dimensional] specifications), and the World Wide Web consortium on synchronized multimedia and usability.

Division Resources

The need for personnel (e.g., in homeland security efforts) in IAD has been partly met by the addition of consultants and students. The level of facilities and equipment resources has remained adequate for the division. Personnel levels have remained flat. The large effort to test biometrics requires new computing resources and massive data storage; it appears that these resources have generally been provided in an adequate and timely manner. An exception is the Meeting Room Transcription project, which captures audio and video data at the rate of 70 gigabytes/hour of meeting. The project needs additional storage and a higher-speed local area network for transmitting data.

For over a decade, IAD has had productive involvement with the FBI and other U.S. security agencies. This involvement has included work in fingerprint, face, and gait biometrics. The steady support of this work has ramped recently with the homeland security initiative, although the technical emphasis has not changed much. IAD has been able to meet the demands of homeland security with knowledge, expertise, and infrastructure (software and hardware) built up over the years. Because of this long-term commitment, the homeland security work has not changed the balance of near-term versus long-term programs in IAD. People and money resources have not been diverted from nonsecurity programs in the division. The customer mix and cooperative relationships of the division have undergone positive changes. In the past, interest and support were mainly from the FBI; now a wider range of government agencies are supporting and referring to NIST recommendations on biometrics.

In previous years, the panel saw little synergy between the biometrics advocacy work done in the Convergent Information Systems Division (CISD) and the biometrics test design and database compilation work done in IAD, though both groups were producing well. CISD facilitated standards, mainly for nongovernment biometrics vendors, and IAD produced databases, designed tests, and wrote standards, mainly for government law-enforcement groups. The new USA PATRIOT Act requirements have brought the activities of both divisions closer. IAD is now testing commercial face recognition systems and is having to deal with commercial interoperability standards, areas in which CISD is also involved. CISD is involved in capture device testing and standards, both of which IAD must deal with in its technology assessment. The two divisions are interacting, and further synergy might enable NIST to lead technology matters related to biometrics more broadly.

The speech and text retrieval work in IAD has traditionally been of interest to industry. More recent text retrieval work in Arabic, ACQUAINT, and speaker verification is of special interest to the government agencies involved in homeland security. IAD has managed to maintain its work related to business while performing this homeland security-related work.

SOFTWARE DIAGNOSTICS AND CONFORMANCE TESTING DIVISION

Technical Merit

The Software Diagnostics and Conformance Testing Division develops software testing tools and methods that improve quality, conformance to standards, and correctness. The division also participates with industry in the development of emerging standards, often taking a leadership role. The division is organized in three groups: Standards and Conformance Testing, Software Quality, and Interoperability. The technical merit of the work done by all three groups continues to be high.

The Standards and Conformance Testing Group develops conformance tests and reference implementations and conducts research on better ways to do conformance testing. The primary area of focus for this group is conformance testing for XML. The group's role expanded significantly this past year beyond conformance tests for XML itself; it now includes related technologies such as ebXML registries and messaging, XSL FO, XML Schema, and XSLT/Xpath, among others. This expanded responsibility is largely at the invitation of industry consortia and working groups, reflecting the group's outstanding track record of working collaboratively with industry, providing technical leadership and unbiased feedback, and facilitating cooperation and coordination among companies.

The Software Quality Group develops methods to automate software testing, develops software diagnostic tools, and conducts research in formal methods. Current projects include Automated Test Generation, Computer Forensics Tool Verification, and Health Care Information Systems. The Automated Test Generation project, which is mature, is currently being transferred to industry organizations that develop mission-critical software, and current work by division staff is focused on industry requests that have arisen during the transfer process. The Computer Forensics Tools Verification project is intended to provide a measure of assurance that tools used in the investigation of computer-related crimes produce results that are both technically and legally valid. The current focus is on testing commercially available disk imaging tools and write-blockers. Test results are reported to manufacturers so that they can improve their products and to law enforcement agencies so that they have a basis for deciding how and when to use particular tools. Work on Health Care Information Systems is focused on helping design a new, Java-based computing environment for the Department of Veterans Affairs.

The Interoperability Group works with other federal government agencies, with the voluntary standards community, and with industry to increase the use of publicly available standards in order to achieve and enhance interoperability. A primary role of this group is that of working with government groups, including the Federal CIO (Chief Information Officers) Council, to apply standards and to develop interoperability tests for IT systems and products that cross several agencies. Current projects include the National Software Reference Library and Smart Card Interoperability. The National Software Reference Library provides a repository of known software, file profiles, and file signatures for use by law enforcement and other organizations in computer forensics investigations. In partnership with GSA in the Government Smart Card (GSC) program, the Smart Card Interoperability project provides standards and tests to accelerate the use of smart card technology, both within the federal government and in the private sector.

Program Relevance and Effectiveness

The Software Diagnostics and Conformance Testing Division supports users and providers of software by facilitating improvements in software quality and interoperability. The division develops products such as reference implementations and conformance test suites, provides technical leadership by chairing standards committees and participating in consortia, and lays the groundwork for overall advances in this field by researching improved methods of conformance testing. NIST's role as an active but neutral third party in standards processes, coupled with the outstanding quality of the conformance tests developed by the division, provides government and industry with a service that is both necessary and unique.

The division leads several ITL-wide initiatives in health informatics that promise to be of significant consequence to the health care delivery community. Foremost of these is a collaborative effort with the Health Level Seven (HL7) standards community. This effort is focused on the HL7 3.0 data model and messaging formats. Until the participation of NIST, there had been very little effort on conformance testing in the HL7 effort. The lack of conformance has been evident in many commercial and public-sector health information systems, despite national mandates to ensure interoperability. NIST's expertise and management of the process is important to the state of the national health care system. The division is beginning to explore how to provide guidance for verification of compliance with the Health Insurance Portability and Accountability Act of 1996. In its early stages, this effort will, if successful, have significant import for the health care community.

The division generally maintains close connection and excellent relationships with its customers, which include industry consortia, private companies, and government agencies. Project goals and metrics are generally responsive to customer requirements, which leads to technically superior results and efficient use of the division's resources. Because project goals and metrics are established at the inception of a project, projects are concluded in a timely manner. A number of key projects have both started and finished this past year, including XSLT, XSL-FO, and the ebXML registries. The division continues to support concluded projects when there is a specific industry request for assistance; this requires very little staff time but is critical for technology transfer.

The Software Diagnostics and Conformance Testing Division has demonstrated impressive success at beginning and concluding projects at appropriate times. Given the wide range of standards activities currently under way, the division shows excellent judgment in selecting efforts where it can have the most significant impact.

STATISTICAL ENGINEERING DIVISION

Technical Merit

The goal of the Statistical Engineering Division is to advance measurement science and technology through collaboration on NIST multidisciplinary research projects by the development of statistical methods for measurement and metrology and by the application of statistical methodology to the collection and analysis of data critical to NIST scientists and engineers and to U.S. commerce. The division wishes to establish itself as a principal resource for statistical expertise in metrology worldwide.

The primary role of the Statistical Engineering Division is to support research projects in other divisions or laboratories, rather than to develop projects within its own division or directly with industrial partners. The division has an extensive list of interactions with other NIST laboratories. These interactions vary from short-term activities to extensive collaborations requiring the generation of new statistical methodology. In many cases, these efforts are playing a fundamental role in establishing statistical methodology, which can also benefit organizations beyond NIST. Current projects are conducted in the areas of Bayesian metrology, key comparisons, IT performance, process characterization, measurement services, new methods for metrology, Internet products, and special programs. Problems being addressed by the division include the measurement of uncertainty in Standard Reference Materials, support of ITL biometrics methods, the development of a statistical methodology for key comparisons, and the characterization of high-speed optoelectronic devices.

A long-term collaboration between the Statistical Engineering Division and EEEL in the study of the properties of dielectric material has produced new methods for characterizing dielectric materials based on measurements of permittivity and loss tangent. The Statistical Engineering Division is working to develop appropriate statistical techniques for use in assessing methods for combining biometric information in real time.

Work in the area of key comparisons involves interlaboratory comparison studies designed to help determine the degree of equivalence among national measurement standards. The comparisons are chosen by the consultative committees under the International Committee for Weights and Measures. The Statistical Engineering Division is the leading statistical presence working toward a unified statistical framework and to provide guidance to ensure accurate, efficient assessment of equivalence. The division is developing new methods to address problems of estimating a consensus mean and eliciting and handling Type B errors.

Improved measurement of high-speed, next-generation optoelectronic devices (40 to 80 Gbps) is of significance to optical-fiber communications, wireless communication, and Ethernet networks. NIST is working to develop calibration methods for optical reference receivers to support industry characterization of the impulse and frequency response. The division's role has been to produce new methodology to minimize the effect of sources of error, such as time drift, time-base distortion, and timing jitter on the measurement of optical receivers.

The division is expanding its work on Bayesian metrology. Given that Type B error often involves nonverifiable assessments and that posterior distributions are of interest to division clients, attention to this area is appropriate. The division should also consider expanding work in data mining, bioinformatics, and computational statistics.

Program Relevance and Effectiveness

The Statistical Engineering Division is providing high-quality statistical support to collaborators and clients throughout NIST. While most efforts are intra-NIST collaborations, the division has been involved in activities of direct benefit to customers outside NIST. It has been involved in the establishment of baseline data sets for use in the assessment and evaluation of the computational accuracy of statistical software. In the area of key comparisons, the division is working directly with CIPM, national metrology institutes, and regional metrology organizations to establish sound statistical principles for the determination of equivalence of national measurement standards.

The division recognizes that the development of new methodology is a primary component of its role. Many problems require similar methods, such as methods for estimating a consensus mean from results of interlaboratory experiments, or methods for addressing the impact of sources of uncertainty. The division is conducting research retreats to focus on developing such methods to achieve integrated solutions.

The division is developing a review article for the statistics research community with the aim of attracting new researchers to the important issues relevant to key comparisons. The division has produced a variety of approaches to estimate a consensus mean and is considering ways to achieve a unified approach that incorporates the knowledge gained across different efforts. Moving research efforts toward more complete solutions and producing solutions in a form that is most easily transmitted to clients and the statistics community are commendable activities.

The Statistical Engineering Division has increased its efforts to be actively involved in the publication and dissemination of statistical knowledge. Nearly all division statisticians are either presenting results at research conferences or publishing in refereed journals. The division could increase its impact through presentations at Research I universities, participation in organizing conference technical programs, and increased publication in premier statistical journals. At this time, only a few of the division's researchers are publishing in such journals. This would help to reestablish NIST as a recognized leading statistical metrology organization and would help draw the attention of the statistics community to the leading problems in metrology. Increased visibility would also aid in the recruiting of new staff members.

The outreach and education effort of the division is strong. It provides courses and resources such as the *NIST/SEMATECH e-Handbook of Statistical Methods* to the NIST community. This effort helps to promote new collaboration and consulting opportunities.

Division Resources

The distribution of services provided by the Statistical Engineering Division appears to be limited by the current size of the division. Since 1997, the division has undergone a major change in size—it once included 30 members. The current size of 19.4 full-time employees makes it difficult to maintain timely interactions and to meet task demands. New staff members are needed to replace lost capabilities. The division needs to add senior appointments of individuals with strong records of research and of methodological and theoretical development. Additional staff will also be needed if the division expands activities into areas such as data mining, bioinformatics, and hierarchical modeling and computational techniques, which are increasingly important statistical tools.

The division has been successful at fulfilling its consulting role and at identifying opportunities for interaction. Limited staff size, however, has reduced its ability to mentor young researchers and to promote national visibility through publication and society activities. When demands exceed resources, the Statistical Engineering Division should consider reducing the number of traditional services that it provides in order to reallocate resources to higher-priority areas. Such decisions should involve a careful assessment of the impact that the division is having on the projects it supports and the relative ranking of the projects within the ITL and NIST strategic plans.

The morale of the division appears to be generally strong. The division director has introduced an effective professional growth and annual planning and reporting process to reinforce staff investment. A new group structure has also been developed to support intergroup efforts.

The Statistical Engineering Division staff expressed general satisfaction with the available computing resources and with facilities. One long-standing issue, however, is the location of the division at the NIST North campus. This is apparently viewed by many division staff members as a major barrier to more effective interaction with NIST scientists. Accidental interactions are virtually eliminated, and strong initiative is required to maintain loose collaborations. As a result, staff may be more likely to become involved in the data analytic stage of a problem than in its design phase, where their expertise can also have a strong impact on the desired final outcome. Young division researchers have limited interaction with potential clients and with sources of expertise; they can fall into a pattern of research that does not consider the full range of solutions. Creating a satellite office suite for shared use on the main campus should be considered, along with information technology solutions that can enhance communication.

The integration of the Statistical Engineering Division into many of the ITL ventures could be stronger, including new ITL initiatives contributing to nanoscale measurement science and homeland security. For example, the biometrics efforts could take advantage of new criteria for combining information for improved matching capabilities. In addition, the division could substantially contribute, with appropriate experimental design and modeling support, in many experimental and simulation situations, including biometrics and computer security-related efforts.

More organized coordination, at higher administrative levels, of the Statistical Engineering Division's participation in projects would be beneficial and might help alleviate some of the lost participation caused by the North Campus isolation.

CONVERGENT INFORMATION SYSTEMS DIVISION

Technical Merit

The Convergent Information Systems Division (CISD) conducts research on, develops, and increasingly promotes integrated systems, architectures, applications, and infrastructure for the exchange, storage, and manifestation of digital content; it also explores their scalability, feasibility, and realization for new applications. CISD currently applies its competency in electronics, physics, computer science, and engineering to high-impact areas that include homeland security, health care, e-commerce, and knowledge management. The division addresses traditional computer science application challenges as well as those in consumer electronics.

During the past year, the CISD continued to provide industry with standardization and testing services for the exchange, storage, and manifestation of digital content. The division has continued its work in the coordination and standardization of biometric technology and exploratory work in authentication, access control and rights management for digital content.

The projects examined for this assessment had metrics and time lines associated with them; however, the level of detail with which they were described varied across projects. This made it difficult to determine if the milestone dates were being met for all projects. In two cases there did not appear to be a documented deliverable for the project. The division should produce for each project, in a standardized format, a time line showing key expected deliverables.

The work in the area of content packaging and formatting aids in the development and definition of interoperability guidelines for digital content types. This past year, the group completed a file format inventory; a file format study on temporal usage, directed at issues relating to a time-based and compressed full-motion image; and an ATP/file format testbed, directed at issues relating to documenting archive media and to the feasibility of transferring scientific, technical, and medical documents to commercial platforms using the e-book format. The group's Refreshable Tactile Graphic Display (e-book) project addresses the goal of providing access for visually impaired and blind persons to images in e-books and other electronic media by creating a new tactile display technology for viewing images by the sense of touch on a reusable surface.

The work in the area of content encapsulation and decapsulation involves developing interoperable open standards, guidelines, and specifications for rights management of digital content. The group's Internet Trust and Digital Rights Management (DRM) project is aimed at developing guidelines to support trust, assurance, and the use of digital objects in e-commerce. The project's emphasis has been on improving electronics interconnect manufacturing and on assisting the digital products and services market. In 2002, the group reviewed general DRM issues and held a workshop to foster dialogue on technology and policy. The group's Biometrics Systems Research and Biometrics Standards Development project assists industry and government in the evaluation and deployment of biometric technologies by developing middleware standards and their reference implementations and by developing prototypes, test methods, test data, and evaluation techniques for multimodal biometrics technologies.

The work on the quantum communication testbed includes constructing a measurement and standards infrastructure for quantum information technology. The infrastructure contains the testbed, calibration, and development facilities open to the technical community. The testbed is intended to demonstrate quantum communication and cryptographic key distribution at a high data rate (1.25 GHz) and to enable wide-ranging experiments on both the physical- and network-layer aspects of quantum communication system performance. This effort is an important part of the wider NIST quantum information program.

The work in the area of content consumption and digital preservation (content storage) focuses on developing metrology methods, technologies, and standards for digital preservation. The effort includes developing methods for testing the reliability of writable CD/DVD disks, including measurement of the life expectancy of CD-R and DVD-R disks, with a goal of providing an unbiased testing methodology for writable optical media. The effort also includes developing methods to test the compatibility of several writable DVD standards for both consumer electronic and PC-software DVD platforms; it also involves developing procedures and guidelines for testing and managing the archival preservation of electronic records with conventional (magnetic) and optical systems.

In its image quality standards and test corpora work, the group is developing measurements and standards for assessing the image quality of moving pictures to support multimedia operability. The project involves use of the division's moving image quality laboratory for the subjective and objective evaluation of image acquisition, processing, and display quality.

Relevance and Effectiveness

CISD's numerous customers include developers of information technology systems, financial organizations, biometrics firms, and other government agencies. The division collaborates with other ITL divisions and across NIST laboratories. Examples include collaborative work across ITL in the areas of biometrics and trust management, with EEEL on image quality and ICM 82B, with CSTL on the SEA (Science and Energy Alliance) conference, and with the Physics Laboratory on the quantum testbed.

Across its groups, the division is engaged in projects relevant to the NIST special focus areas. Work in digital preservation, data interchange, and biometrics supports the homeland defense and information knowledge management areas; work on file standards supports the health care area; and work on the quantum testbed supports the nanotechnology area.

Almost all of the projects reviewed for this assessment are relevant to the general industry that the division serves, with the exception of the quantum project. Although the project's research is interesting, its applicability to customer needs is not clear, because of the limitations in range and quality of over-the-air quantum cryptography. The testbed does not appear capable of addressing some of the fundamental interference issues that must be resolved before quantum systems can be deployed.

CISD has served industry as a catalyst primarily by widely disseminating its work. Staff members contributed approximately 16 publications and more than 30 technical presentations during the past year, and they facilitated several workshops. Their presentation on digital preservation is significant. The Library of Congress highlighted the NIST work in its plan for the National Digital Information and Infrastructure Preservation Program.

The CISD has published the results of its DRM and file format studies, which, in conjunction with image comparison tools, are critical for the analysis of temporal playback and compression. The division has developed new equipment to support research and development in the areas of image-quality analysis and biometrics, as well as new equipment for quantum laboratories.

The division has expanded its involvement with external organizations, including the Advanced Television Systems Committee, DVD Association, High Density Storage Association, Financial Services Technology Consortium, Biometrics Consortium, Open eBook Forum, International Committee for Information Standards, Society for Motion Picture and Television Engineers, and Optical Storage

Technology Association. It has also completed impact studies for e-books, biometrics, and the digital TV application software environment (DASE) and has improved its dissemination of results to relevant industries by making its Web site more user-friendly and by using the Web site as a vehicle for access to new division products.

With its customers, the division should conduct a regular review of progress against the time lines and deliverables for projects (discussed above) as one effective way of determining whether the programs are relevant and whether they meet customer needs.

Division Resources

It appears that the CISD funding derived from ATP may disappear in FY 2004 (its FY 2002 level was $426,000; its FY 2003 level is $320,000). This may affect the biometrics multimodal work, as well as other projects deriving significant funding from the ATP.

The quality of division facilities has improved. With the infusion of infrastucture funding, equipment has been constantly improving; in general, it is fairly new and nearly state-of-the-art technology. The digital preservation work would benefit from updated DVD test and microscopy equipment; video quality tests would benefit from an updated screen and video cameras; and quantum technology testbeds, from a new oscilloscope. The digital preservation, quantum technology, and biometrics work would progress better with the addition of a full-time employee to each project.

The panel's concern in the FY 2002 assessment about funding and staff shortfalls has been addressed by the division's obtaining additional funds for the quantum work and closing a $450,000 shortfall by preparing successful funding proposals and by engaging in interdivisional work. In response to the panel's urging that needs arising from the large number of student and guest researchers be assessed, the division has maintained a 1-to-1 ratio of full-time staff to students in the past year and has selected guest researchers for their ability to be creative self-starters.

The CISD has revised its business plan to a 2-year R&D plan that can more flexibly adjust to the shifting needs of industry and government.

Appendixes

A

Charge to the Board and Panels

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

NOV 21 2002

MEMORANDUM FOR Board on Assessment of NIST Programs and its Panels

From: Arden L. Bement, Jr.
Director

Subject: Charge to the National Research Council Board on Assessment of NIST Programs for the FY2003 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 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 FY2003.

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 FY2003, I ask that the Board on Assessment continue your longstanding focus on assessing the technical merit 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 current and future customers. Potential demand for NIST measurements 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 FY2003 assessment of the NIST Laboratories on three factors:

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

As part of its assessment of these three factors, I ask the Board and its Panels to consider the adequacy of the Laboratories' facilities, equipment, and human resources to enable the Laboratories to fulfill their mission and meet their customers' needs. At the October 16 Workshop, NIST and the Board briefly discussed possible indicators of performance for each of the factors that may provide guidance to the Board and its Panels in the assessment process. I look forward to discussing these indicators and their potential use with the Board in more detail at the December meeting.

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 used by NIST internally for continuous improvement in each area of evaluation and externally for reporting to key stakeholders on the quality, relevance, and performance of the NIST laboratories. NIST's key stakeholders, including the Department of Commerce, the Administration, and Congress, use your findings to help 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) and the Office of Management and Budget (OMB) R&D investment criteria. The Board's annual published assessment is a thorough and comprehensive document of great value to NIST and our stakeholders. I am pleased that the Board agreed at the October 16 Workshop to provide a brief "Stakeholder's Statement" document as part of the FY2003 assessment that will address issues the Board believes should be of interest to NIST's key stakeholders. This document will be valuable in helping to more broadly disseminate the Board's key findings.

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: Senior Management Board
Program Office
Scott Weidman

B

Agendas for Meetings of the Board on Assessment of NIST Programs

DECEMBER 12, 2002

National Institute of Standards and Technology, Gaithersburg, Maryland

Wednesday, December 11

7:00 p.m.	Dinner, Board and new Panel members

Thursday, December 12

Open Session

8:00 a.m.	Welcome and Introductions Linda Capuano, Chair, NRC Board on Assessment of NIST Programs
8:15 a.m.	Introduction to NRC and Overview of Board/Panel Operations Scott Weidman, Director, Board on Assessment of NIST Programs, NRC
8:45 a.m.	NIST Director's Address Arden Bement, Director, NIST
9:30 a.m.	New Panel members continue with orientation Board goes into Executive Session

Closed Session

9:30 a.m.	Discussion of Board Balance and Composition
10:30 a.m.	Fiscal Year 2003 Assessment Discussion • Review conclusions from fiscal year 2002; identify themes for fiscal year 2003 assessment

- Discuss proposed three-layer report structure for maximizing usefulness of report for multiple audiences
- Discuss possible use of performance indicators in assessment

Open Session

12:00 noon Lunch

Closed Session

1:00 p.m. Fiscal Year 2004-2005 Assessment Discussion
- Discuss possible biennial assessment process proposed for fiscal year 2004-2005

Open Session

2:15 p.m. Open Discussion with NIST OU Heads
- Themes for fiscal year 2003 assessment
- Proposed changes to report structure, use of performance indicators (for fiscal year 2003)
- Proposed shift to biennial process (for fiscal year 2004-2005)

Closed Session

3:30 p.m. Wrap Up

4:00 p.m. Adjourn

MAY 14-15, 2003

National Academies Green Building, Washington, D.C.

Meeting Objectives

- Development of the report's principal findings and recommendations
- Discussion of specific questions and themes from 2003 and their placement in the report
- Examination of the review process and useful modifications
- Discussion of report format
- Discussion of concerns and questions with NIST senior staff

Wednesday, May 14

Closed Session

8:30 a.m. Welcome and Statement of Meeting Objectives

8:35 a.m. Review of Panel Findings
Each panel chair to summarize (15 minutes each) top findings by his or her panel

10:00 a.m. Break

10:15 a.m. Continue with Panel Summaries

11:00 a.m.	Develop Consolidated List of Conclusions for 2003 • Decide how to cover these topics in the report • Identify which assessment issues and concerns to discuss tomorrow with NIST senior staff • Determine what to say about specific themes for 2003: facilities, intellectual property, homeland security, balance between service and research, and performance indicators
12:00 noon	Lunch
12:45 p.m.	Complete Plans for Presentation to NIST Leadership
1:15 p.m.	Discussion of Proposed Revisions to the Review Process • Division site visits • Size of panels; how to increase their importance to the assessments • Process of selecting panel members • Board's charge
2:45 p.m.	Break
3:00 p.m.	Continue Discussion
5:00 p.m.	Adjourn for Day

Thursday, May 15

Closed Session

8:30 a.m.	Discussion of Possible Biennial Report Process
10:30 a.m.	Break
10:45 a.m.	Converge on Process Decisions and Plan for the Discussion with NIST

Open Session

12:00 noon	Lunch with NIST Senior Staff
1:00 p.m.	Discussion with NIST Senior Staff • Discussion of concerns and open questions from the 2003 site visits • Lessons learned regarding performance indicators • Any major modifications to the assessment process and report structure • Biennial report process
3:00 p.m.	Adjourn

C

Functions of NIST

NIST STATUTORY CHARTER

Unlike most federal laboratories that derive their missions from those of their parent agencies, NIST is chartered by Congress in broad and comprehensive legislation. First written in 1900 and signed into law in 1901, the NIST authorizing legislation is periodically updated. In 1988, in a sweeping rewrite of the authorization, the Congress placed NIST in the forefront of federal efforts to improve the use of technology in the competition for global markets.

The Omnibus Trade and Competitiveness Act of 1988 augmented NIST's functions and capabilities. Specifically, NIST received new capability to carry out its mandate to help private-sector firms capitalize on advanced technology. The act also reconfirmed the importance of NIST's existing capabilities. It asserted that NIST's measurements, calibrations, and quality assurance techniques were the underpinning of U.S. commerce, technological progress, improved product reliability, improved manufacturing processes, and public safety. NIST continues to have a unique responsibility to promote economic growth by working with industry to develop and apply technology, measurements, and standards.

The functions and programs enacted through this legislation complement the existing functions and programs extremely well, and have increased dramatically the leverage and economic impact of the Institute.

The Omnibus Trade and Competitiveness Act directed NIST

> to modernize and restructure to augment its unique ability to enhance the competitiveness of American industry while maintaining its traditional function as lead national laboratory for providing the measurements, calibrations, and quality assurance techniques that underpin United States commerce, technological progress, improved product reliability and manufacturing processes, and public safety; to assist

NOTE: This appendix, which includes information on NIST's statutory charter and mission, was provided by NIST in the course of the fiscal year 2003 reviews and thus was not authored by the Board on Assessment of NIST Programs.

> private-sector initiatives to capitalize on advanced technology; to advance, through cooperative efforts among industries, universities, and government laboratories, promising research and development projects that the private sector can optimize for commercial and industrial applications; and to promote shared risks, accelerated development, and pooling of skills that will be necessary to strengthen America's manufacturing industries.

In the enumeration of NIST's functions in the act, two are of particular note as they reinforce the existing mission:

> (1) to assist industry in the development of technology and procedures needed to improve quality, to modernize manufacturing processes, to ensure product reliability, manufacturability, functionality, and cost-effectiveness and to facilitate the more rapid commercialization, especially by small- and medium-sized companies throughout the United States, of products based on new scientific discoveries in fields such as automation, electronics, advanced materials, biotechnology, and optical technologies;
>
> (2) to develop, maintain, and retain custody of the national standards of measurement, and provide the means and methods for making measurements consistent with those standards, including comparing standards used in scientific investigations, engineering, manufacturing, commerce, industry, and educational institutions with standards adopted or recognized by the Federal Government.

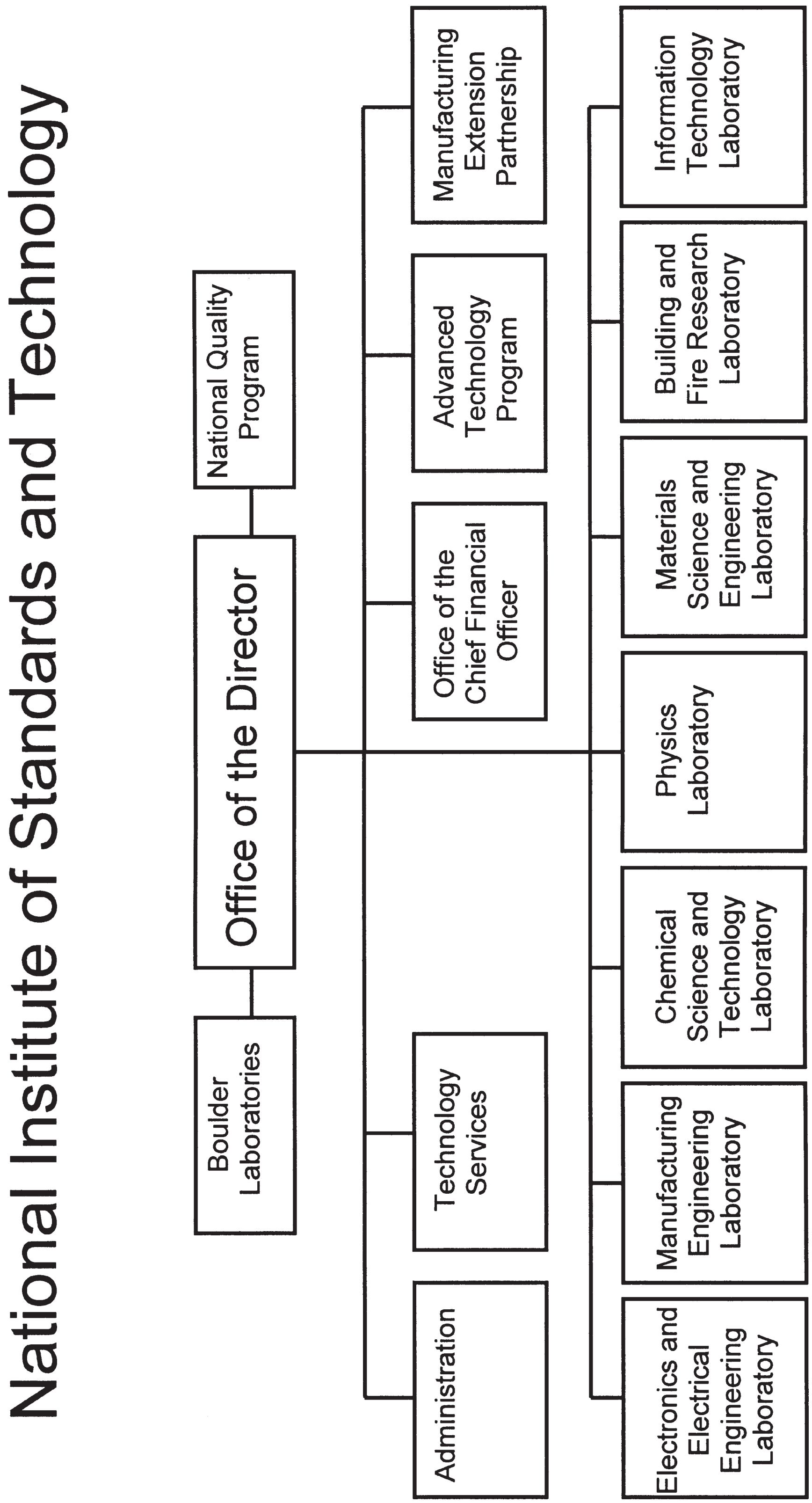
MISSION OF NIST

NIST's primary mission is to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. It carries out this mission through a portfolio of four major programs:

- The Measurements and Standards Program promotes the U.S. economy and public welfare by providing technical leadership for the Nation's measurement and standards infrastructure, and assuring the availability of essential reference data and measurement capabilities.
- The Advanced Technology Program stimulates U.S. economic growth by developing high risk and enabling technologies through industry-driven cost-shared partnerships.
- The Manufacturing Extension Partnership Program strengthens the global competitiveness of smaller U.S.-based manufacturing firms by providing information and assistance in adopting new, more advanced manufacturing technologies, techniques, and business best practices.
- The National Quality Program enhances the competitiveness, quality, and productivity of U.S. organizations for the benefit of all citizens, manages the Malcolm Baldrige National Quality Award, and provides global leadership in promoting quality awareness.

D

NIST Organization


National Institute of Standards and Technology
Office of the Director
Boulder Laboratories
National Quality Program
Administration
Technology Services
Office of the Chief Financial Officer
Advanced Technology Program
Manufacturing Extension Partnership
Electronics and Electrical Engineering Laboratory
Manufacturing Engineering Laboratory
Chemical Science and Technology Laboratory
Physics Laboratory
Materials Science and Engineering Laboratory
Building and Fire Research Laboratory
Information Technology Laboratory

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Electronics and Electrical Engineering Laboratory

Electricity Division
Semiconductor Electronics Division
Radio-Frequency Technology Division
Electromagnetic Technology Division
Optoelectronics Division
Magnetic Technology Division
Office of Microelectronics Programs
Office of Law Enforcement Standards

Manufacturing Engineering Laboratory

Precision Engineering Division
Manufacturing Metrology Division
Intelligent Systems Division
Manufacturing Systems Integration Division
Fabrication Technology Division

Chemical Science and Technology Laboratory

Biotechnology Division
Process Measurements Division
Surface and Microanalysis Science Division
Physical and Chemical Properties Division
Analytical Chemistry Division

Physics Laboratory

Electron and Optical Physics Division
Atomic Physics Division
Optical Technology Division
Ionizing Radiation Division
Time and Frequency Division
Quantum Physics Division (JILA)

Materials Science and Engineering Laboratory

Ceramics Division
Materials Reliability Division
Polymers Division
Metallurgy Division
NIST Center for Neutron Research

Building and Fire Research Laboratory

Materials and Construction Research Division
Building Environment Division
Fire Research Division
Office of Applied Economics and Standards and Code Services

Information Technology Laboratory

Mathematical and Computational Sciences Division
Advanced Networking Technologies Division
Computer Security Division
Information Access Division
Convergent Information Systems Division
Software Diagnostics and Conformance Testing Division
Statistical Engineering Division

E

Acronyms and Abbreviations

AC—alternating current
ACBM—Center for Advanced Cement-Based Materials
ACD—Analytical Chemistry Division
ACE—Automatic Content Extraction
ACI—American Concrete Institute
ACM—Association for Computing Machinery
AEC/FM—architecture, engineering, construction, and facility management
AES—Advanced Encryption Standard
AFM—atomic force microscopy/microscope
AIGER—American Industry/Government Emissions Research
AMAG—ISMT Advanced Metrology Advisory Group
AML—Advanced Measurement Laboratory
AMO—atomic, molecular, and optical
ANSI—American National Standards Institute
AODV—ad hoc on-demand distance vector
AQUAINT—Advanced Question and Answering for Intelligence
ARDA—Advanced Research and Development Activity
ARL—Army Research Laboratory
ARTI—Air Conditioning and Refrigeration Technology Institute
ASHRAE—American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME—American Society of Mechanical Engineers
ASTM—American Society for Testing and Materials
ATP—Advanced Technology Program
ATR—attenuated total reflectance

BACnet—Building Automation and Control Network

BB—Bloch-Bloembergen
BEC—Bose-Einstein condensate
BEES—Building for Environmental and Economic Sustainability
BFRL—Building and Fire Research Laboratory
Bio-MEMS—bio-microelectromechanical system(s)
BVL—Biomarker Validation Laboratory

CAD—computer-aided design
CAE—computer-aided engineering
CAM—computer-aided manufacturing
CARB—Center for Advanced Research in Biotechnology
CARS—coherent anti-Stokes Raman spectroscopy
CBR—chemical, biological, or radiological
CCQM—Consultative Committee for Amount of Substance
CD—critical dimension; compact disk
CE—capillary electrophoresis
CEC—California Energy Commission
CET—capacitance equivalent thickness
CHRNS—Center for High Resolution Neutron Scattering
CIF—Common Industry Format
CIO—chief information officer
CIPM—Comité International des Poids et Mésures
CISD—Convergent Information Systems Division
CISPR—International Special Committee on Radio Interference
CIS2—CIMsteel Integration Standards
CLEF—Cross-Language Evaluation Forum
CMM—coordinate measuring machine
CMOS—complementary metal-oxide semiconductor
CMVP—Cryptographic Module Validation Program
CNBT—Cold Neutrons for Biology and Technology
CORM—Council for Optical Radiation Measurements
CRADA—cooperative research and development agreement
CRDS—cavity ring-down spectrometer
CRM—Certified Reference Material
CSTL—Chemical Science and Technology Laboratory
CW—continuous wave

DARPA—Defense Advanced Research Projects Agency
DASE—digital TV application software environment
DAVE—Data Analysis and Visualization Environment
DC—direct current
DCS—disk-chopper spectrometer
DLMF—Digital Library of Mathematical Functions
DNA—deoxyribonucleic acid
DNSSec—Domain Name System Security
DOD—Department of Defense

DOE—Department of Energy
DUC—Document Understanding Conference
DVD—digital versatile disk

EARS—Effective Affordable Reusable Speech-to-text
EBIT—electron-beam ion trap
ECCI—Electronic Commerce of Component Information
EDRN—Early Detection Research Network
EEEL—Electronics and Electrical Engineering Laboratory
EIA—Electronics Industry Association
EM—electromagnetic
EMC—electromagnetic compatibility; Enhanced Machine Controller
EOT—equivalent oxide thickness
EPA—Environmental Protection Agency
EUV—extreme ultraviolet

FASCAL—Facility for Automatic Spectroradiometric Calibrations
FBI—Federal Bureau of Investigation
FDA—Food and Drug Administration
FDD—fault detection and diagnostics
FDS—Fire Dynamics Simulator
FIB—focused ion beam
FPD—flat panel display
FRD—Fire Research Division
FTE—full-time equivalent
FTIR—Fourier transform infrared

GC/MS—gas chromatography/mass spectrometry
GD&T—geometric dimensional tolerancing
GEC—Gaseous Electronics Conference
GISRA—Government Information Security Reform Act
GLASS—GMPLS (generalized multi-protocol label switching) Lightwave Agile Switching Simulator
GMO—genetically modified organism
GPS—Global Positioning System
GSA—General Services Administration
GSC—Government Smart Card
GTEM—Gigahertz Transverse Electromagnetic Mode

HACR—high accuracy cryogenic radiometer
HDTV—high-definition television
HFBS—high-flux backscattering spectrometer
HL7—Health Level Seven
HUD—Department of Housing and Urban Development
HVAC/R—heating, ventilation, air conditioning, and refrigeration
HYPERCON—relating to high-performance concrete (a program)

IAD—Information Access Division
IAQ—indoor air quality
IC—integrated circuit
ICM—Internet Commerce for Manufacturing
ICMS—Intelligent Control of Mobility Systems
ICRU—International Commission on Radiation Units and Measurements
IDEM—Integrated Dimensional and Electrical Metrology
IDS—intrusion detection system
IEA—International Energy Agency
IEC—International Electrotechnical Commission
IEEE—Institute of Electrical and Electronics Engineers
IETF—Internet Engineering Task Force
IKE—Internet Key Exchange
INAA—instrumental neutron activation analysis
INEX—Initiative for Evaluation of XML Retrieval
IOAC—Intelligent Open Architecture Control
IP—Internet Protocol; intellectual property
IPC—Institute for Packaging of Electronic Circuits
IPSec—Internet Protocol Security
IR—infrared
ISA—Instrumentation, Systems, and Automation Society
ISD—Intelligent Systems Division
ISMT—International SEMATECH
ISO—International Organization for Standardization
ISSC—Information System to Support Calibrations
IT—information technology
ITL—Information Technology Laboratory
ITRS—International Technology Roadmap for Semiconductors
IUSR—Industry Usability Reporting
IVD—in vitro diagnostics

JAIN—JAVA Advanced Intelligent Network
JEDEC—Joint Electron Device Engineering Council

LC—liquid chromatography
LCD—liquid crystal display
LED—light-emitting diode
LSI—length-scale interferometer
LTCC—low-temperature co-fired ceramics

MALDI—matrix-assisted laser desorption ionization
MAP—measurement assurance program
MARS—Mobile Autonomous Robot Software
MatML—Materials Property Data Markup Language
MBE—molecular beam epitaxy
MCSD—Mathematical and Computational Sciences Division

MDA—Missile Defense Agency
MEL—Manufacturing Engineering Laboratory
MEMS—microelectromechanical system(s)
MIRF—Medical-Industrial Radiation Facility
MMD—Manufacturing Metrology Division
MOS—metal-oxide semiconductor
MOSFETS—metal-oxide semiconductor field-effect transistors
MPLS—multiprotocol label switching
MRA—Mutual Recognition Agreement
MRAM—magnetic random access memory
MS—mass spectrometry/spectrometer
MSEL—Materials Science and Engineering Laboratory
MSID—Manufacturing Systems Integration Division
MSL—Measurement and Standards Laboratories
MTD—Magnetic Technology Division

NASA—National Aeronautics and Space Administration
NC—numerical control
NCI—National Cancer Institute
NCNR—NIST Center for Neutron Research
NDP—neutron depth profiling
NDRL—Notre Dame Radiation Laboratory
NEMI—National Electronics Manufacturing Initiative
NEPA—National Environmental Policy Act
NFG—nonfederal government (agencies)
NG-3—neutron guide 3
NIAP—National Information Assurance Partnership
NIDCR—National Institute of Dental and Craniofacial Research
NIF—National Ignition Facility
NIH—National Institutes of Health
NIST—National Institute of Standards and Technology
NMI—National Metrology Institute
NMR—nuclear magnetic resonance
NOAA—National Oceanic and Atmospheric Administration
NPL—National Physical Laboratory
NRC—National Research Council
NRL—Naval Research Laboratory
NSE—neutron spin echo
NSF—National Science Foundation
NTCIR—NAGSIS Test Collection for Information Retrieval systems
NTRM—NIST-Traceable Reference Materials

OA—other agencies
OAE—Office of Applied Economics
OLES—Office of Law Enforcement Standards
OMAC—Open Modular Architecture Controller

OMP—Office of Microelectronics Programs
OOMMF—Object Oriented Micromagnetic Framework
OSTP—Office of Science and Technology Policy

PAC—Program Advisory Committee
PARCS—Primary Atomic Reference Clock in Space
PC—personal computer
PCR—polymerase chain reaction
PCSRF—Process Control Security Requirements Forum
PDB—Protein Data Bank
PDMS—polydimethylsiloxane
PED—Precision Engineering Division
PGAA—prompt gamma activation analysis
PIMM—pulsed inductive microwave magnetometer
PL—Physics Laboratory
PMD—polarization-mode dispersion
POCT—point-of-care testing
PPE—Predictive Process Engineering
PTB—Physikalisch-Technische Bundesanstalt
PVTt—pressure, volume, temperature, time

QH—quantum Hall

R&D—research and development
RCS—real-time control system; radar cross-section
REIS—Research and Engineering of Intelligent Systems
REML—RF-EM Field Metrology Laboratory
RF—radio frequency
RIA—Robotics Industry Association
RIF—reduction in force
RIMS—resonance ionization mass spectrometry/spectrometer
RNAA—radiochemical neutron activation analysis
RTC—real-time control

SANS—small-angle neutron scattering
SCM—scanning capacitance microscopy/microscope
SCUBA—Submillimeter Common-Use Bolometer Array
SEA—Science and Engineering Alliance
SED—Semiconductor Electronics Division
SEM—scanning electron microscopy/microscope
SEMATECH—Semiconductor Manufacturing Technology Consortium
SEMPA—Scanning Electron Microscopy with Polarization Analysis
SET—single-electron transistor
SFA—Strategic Focus Area
SI—International System (of units)
SIA—Semiconductor Industry Association

SIM—Sistema Interamericano Metrología
SIMS—secondary ion mass spectroscopy
SIP—Session Initiation Protocol
SIRCUS—spectral irradiance and radiance calibration with uniform sources
SIS—superconductor-insulator-superconductor
SLP—Service Life Prediction
SM3—Single Molecule Manipulation and Measurement
SOC—system-on-a-chip
SPHERE—Simulated Photodegradation by High Energy Radiant Exposure
SPINS—spin-polarized triple-axis spectrometer
SRD—Standard Reference Database
SRM—Standard Reference Material
STEP—Standard(s) for the Exchange of Product Model Data
STM—scanning tunneling microscopy/microscope
STR—short tandem repeat
STRS—Scientific and Technical Research and Services
STS—submillimeter topographic spectroscopy
SURF—Synchrotron Ultraviolet Radiation Facility

T-DES—Triple Data Encryption Standard
TDT—Topic Detection and Tracking
TEM—transmission electron microscopy/microscope
TIDES—Translingual Information Detection and Summarization
TIMS—thermal ionization mass spectrometry/spectrometer
TOF—time of flight
TRC—Thermodynamics Research Center
TREC—Text Retrieval Conference
TSA—Transportation Security Administration
TXR—Thermal IR Transfer Radiometer

UE/ASV—ultrasonic extraction/anodic stripping voltammetry
UGV—unmanned ground vehicle
ULSI—ultralarge-scale integration
UPR—undulations per revolution
USAEDS—U.S. Atomic Energy Detection System
USANS—ultrasmall-angle neutron scattering
USA PATRIOT—Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism (Act)
USCAR—United States Council for Automotive Research
USPS—United States Postal Service
UTC—coordinated universal time
UV—ultraviolet
UWB—ultrawideband

VCBT—Virtual Cybernetic Building Testbed
VCCTL—Virtual Cement and Concrete Testing Laboratory

VIS—visible
VOC—volatile organic compound
VUV—vacuum ultraviolet

WANET—wireless ad hoc network
WDM—wavelength-division multiplexing
WTC—World Trade Center

XCALIBIR—X-ray Optics Calibration Interferometer
XML—extensible markup language

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Biographies of Board Members

MEMBERS AT LARGE

Linda Capuano (Chair) is vice president, Technology Strategy, Honeywell, with overall customer and product responsibility. Her past experience includes research and development (R&D) management with responsibility for selecting and managing R&D programs and new business opportunities in a variety of technologies and experience in high-level review of government research programs. She has previously held positions at Conductus and IBM Corporation. She served on the Department of Energy (DOE) Task Force on Alternative Futures for the DOE National Laboratories (the "Galvin Task Force").

David C. Bonner is vice president for R&D and chief technology officer at Cabot Corporation. His previous positions include global director of Rohm and Haas Company's Polymer Technology Center; senior vice president for technology and engineering, Westlake Group; senior vice president and chief technical officer, Premix; vice president for research and development, B.F. Goodrich; and associate professor of chemical engineering at Texas A&M University. Dr. Bonner has published more than 50 peer-reviewed articles and holds a Ph.D. in chemical engineering from the University of California, Berkeley. He served as a member of the National Research Council's Committee on the Industrial Environment Performance Metrics and was a member of the Board on Chemical Sciences and Technology.

Herwig Kogelnik is adjunct vice president for photonics research at Bell Laboratories, Lucent Technologies. He is known for his pioneering work on lasers, holography, and optical guided-wave devices and for his leadership of optical communications research. He is a member of the National Academy of Sciences and the National Academy of Engineering.

Mark B. Myers retired from the Xerox Corporation at the beginning of 2000, after a 36-year career in its research and development organizations. He was the senior vice president in charge of corporate research, advanced development, systems architecture, and corporate engineering from 1992 to 2000.

His responsibilities included the corporate research centers, such as Palo Alto Research Center in Palo Alto, California. During this period, he was also a member of the senior management committee in charge of the strategic direction setting of the company. Currently, he is Visiting Executive Professor in the Management Department at the Wharton Business School, the University of Pennsylvania, where his research interests include identifying emerging markets and technologies to enable growth in new and existing companies with special emphases on technology identification and selection, product development, and technology competencies. He holds a bachelor's degree from Earlham College and a doctorate from Pennsylvania State University. He serves on the NRC's Science, Technology, and Economic Policy Board and currently co-chairs the NRC study of Intellectual Property in the Knowledge Based Economy.

Thomas A. Saponas is a senior vice president and chief technology officer of Agilent Technologies as well as director of Agilent Laboratories. His responsibilities include developing the company's long-term technology strategy and overseeing the alignment of the company's objectives with its centralized R&D activities. He has more than 27 years of experience in electrical engineering, refined over the course of his career with Hewlett-Packard Company, where he began in 1972 as a design engineer in the company's Automatic Measurement Division and went on to become vice president and general manager of the Electronic Instruments Group. In 1986, he was selected to serve as a White House fellow and served as special assistant to the Secretary of the Navy for a year on leave from Hewlett-Packard. He earned a B.S. in electrical engineering and computer science and an M.S. in electrical engineering, both from the University of Colorado.

Eugene Sevin is an independent consultant. His research interests are in nuclear and conventional weapons effects, hardened facility design, and computational structural mechanics. He formerly served with the U.S. Department of Defense as deputy director, space and missiles systems, and with the defense nuclear agency as assistant to the deputy director (science and technology) for experimental research. Other positions that Dr. Sevin has held include professor of mechanical engineering at the Technion, Israel Institute of Technology (IIT), and head, mechanical engineering at Ben Gurion University of the Negev, Israel. He earned a B.S. degree in mechanical engineering from IIT, an M.S. degree from the California Institute of Technology, and a Ph.D. in applied mechanics from IIT. He is a member of the National Academy of Engineering. He is currently a member of the NRC Committee on Army S&T for Homeland Defense and has served on the NRC Committee on Oversight and Assessment of Blast-effects and Related Research.

EX OFFICIO MEMBERS

Panel for Electronics and Electrical Engineering

Constance J. Chang-Hasnain (Chair) is a professor of electrical engineering and computer science at the University of California, Berkeley. Her research interests are in novel semiconductor optoelectronic device and material technologies for optical communications and in ultrahigh-capacity optical networks and systems enabled by novel components. Before coming to Berkeley in 1992, she spent 5 years at Bellcore. In 1997 she founded BANDWIDTH9, Inc.; she is currently its chief technical officer. She received a B.S. from the University of California, Davis, and an M.S. and Ph.D. from the University of California, Berkeley, all in electrical engineering. She is a fellow of the Institute of Electrical and

Electronics Engineers (IEEE) and of the Optical Society of America and has been a Packard fellow, Sloan fellow, and National Young Investigator.

Robert R. Doering (Vice Chair) is a senior fellow in Silicon Technology Development at Texas Instruments (TI). Currently, his primary area of responsibility at TI, where he has been since 1980, is technology strategy. His previous positions at TI include those of manager of future-factory strategy, director of scaled-technology integration, and director of the Microelectronics Manufacturing Science and Technology Program. He received a B.S. degree in physics from the Massachusetts Institute of Technology and a Ph.D. in physics from Michigan State University. He is co-chair of the International Technology Roadmap for Semiconductors and serves on the Corporate Associates Advisory Committee of the American Institute of Physics. He is a senior member of IEEE.

Panel for Manufacturing Engineering

Marvin F. DeVries (Chair) is a professor of mechanical engineering, University of Wisconsin at Madison. He is an expert on metal-cutting processes and computer-integrated manufacturing. His current research focuses on material removal processes and computer-aided manufacturing. He is a fellow of the American Society of Mechanical Engineers, the Institute of Production Engineers, and the Society of Manufacturing Engineers.

Richard A. Curless (Vice Chair) is vice president of Product and Technology Development for UNOVA Manufacturing Technologies, located in Cincinnati, Ohio. His responsibilities include technology development and transfer, technical support services, and product development. He has 35 years of experience in the machine tool industry. His previous positions include chief engineer, manager of R&D projects, and manager of advanced technology at Cincinnati Milacron. He currently serves on various technical advisory boards and committees, including TechSolve Board of Directors, the National Center for Manufacturing Sciences' Strategic Technical Board, and the Association for Manufacturing Technology's Technology Issues Committee.

Panel for Chemical Science and Technology

James W. Serum (Chair) is founder of SciTek Ventures, a consulting company that works with early-stage technology companies. Before founding SciTek in early 2002, he was executive vice president and chief operating officer of Viaken Systems, Inc., a hosted informatics solutions provider for the life sciences, providing solutions for biotechnology, pharmaceutical, and agricultural R&D companies. Before helping to found Viaken in 1999, he spent 26 years at Hewlett-Packard (HP), where he worked on mass spectrometry instrumentation. In 1992, Dr. Serum was named general manager for mass spectrometry, infrared, and protein chemical systems, and in 1994 he founded HP's Bioscience Products business before returning to the East Coast as a senior scientist and chair of the HP Pharmaceutical Business Council. He received a B.A. in chemistry from Hope College and a Ph.D. degree in organic chemistry from the University of Colorado.

Alan Campion (Vice Chair) is Dow Chemical Company Professor and University Distinguished Teaching Professor in the Department of Chemistry and Biochemistry of the University of Texas, Austin. His research interests lie in the general area of surface physics and chemistry, with a particular focus on the spectroscopy of molecules adsorbed on single crystal surfaces. His laboratory is perhaps best known for its pioneering work in surface Raman spectroscopy. Current work is focused on developing a mechanistic understanding of surface-enhanced Raman scattering, on single-molecule Raman spectroscopy, and on the development of Raman near-field scanning optical microscopy. Professor Campion received the B.A. in chemistry from New College (Florida) and a Ph.D. in chemical physics from the University of California, Los Angeles, and he was a National Science Foundation National Needs Postdoctoral Fellow at the University of California, Berkeley. He has been an Alfred P. Sloan Fellow, Camille and Henry Dreyfus Teacher-Scholar, and Guggenheim Fellow, and he was awarded the Coblentz Memorial Prize in Molecular Spectroscopy in 1987.

Panel for Physics

Duncan T. Moore (Chair) is the Rudolf and Hilda Kingslake Professor of Optical Engineering and a professor of biomedical engineering at the University of Rochester. He is also a special assistant to the university president and executive director of the University, Industry and Government Partnership for Advanced Photonics. From the fall of 1997 to December 2000, Dr. Moore served in the position of associate director for technology in the White House Office of Science and Technology Policy (OSTP). In this position, he worked on technology policy, including that related to the Next Generation Internet, Clean Car Initiative, technology for elders, crime technologies, and NASA. From January through May 2001, Dr. Moore served as special adviser to the acting director of OSTP. Dr. Moore has extensive experience in the academic, research, business, and governmental areas of science and technology. He is an expert in gradient-index optics, computer-aided design, and the manufacture of optical systems. Dr. Moore is the founder and former president of Gradient Lens Corporation of Rochester, New York, a company that manufacturers the high-quality, low-cost Hawkeye boroscope. In 1996, Dr. Moore served as president of the Optical Society of America (OSA). From January 2001 to the present, he has served as senior science advisor at OSA. In 1999, he received the National Engineering Award of the American Association of Engineering Societies. He was the recipient of the 2001 OSA Leadership Award. He is a member of the National Academy of Engineering.

Robert L. Byer (Vice Chair) is a professor of applied physics and the director of the Hansen Experimental Physics Laboratory at Stanford University. He is recognized for his contributions to the science, engineering, and art of solid-state lasers, optical parametric oscillators, and nonlinear optics. His current research interests include laser sources and interferometer configurations for gravitational wave detection, global remote sensing using tunable solid-state lasers, laser electron acceleration, and studies of ultrafast laser interaction with matter. He has a B.A. in physics from the University of California, Berkeley and M.S. and Ph.D. degrees in applied physics from Stanford University. He is a fellow of OSA, IEEE, American Physical Society, and the American Association for the Advancement of Science and is a member of the National Academy of Sciences and of the National Academy of Engineering. He has served as president of OSA and of the IEEE Lasers and Electro-optics Society.

Panel for Materials Science and Engineering

David W. Johnson, Jr. (Chair) is the retired director of the Applied Materials Research Department at Agere Systems. His expertise is in ceramic materials development and processing, specifically, powder preparation methods, magnetic devices, and optical fiber glasses. He is a member of the National Academy of Engineering and a past president of the American Ceramic Society.

Katharine G. Frase (Vice Chair) is director of World Wide Packaging Development for the IBM Microelectronics Division. She is responsible for all process development and design/modeling methodology for organic and ceramic chip packaging for IBM. Her research interests include mechanical properties/structural interactions in composites, high-temperature superconductors, solid electrolytes (fast ionic conductors), ceramic powder synthetic methods, and ceramic packaging. She received an A.B. in chemistry from Bryn Mawr College and a Ph.D. in materials science and engineering from the University of Pennsylvania. She chaired an IBM/NRC workshop on lead solder reduction actions and in 1998 served as the packaging assurance manager for IBM worldwide.

Panel for Building and Fire Research

Robert A. Altenkirch (Chair) is president of the New Jersey Institute of Technology (NJIT). He is an expert in flame spreading, combustion at reduced gravity, and heat and mass transfer processes in combustion. Before coming to NJIT, he was vice president for research at Mississippi State University from 1998 to 2002, and before that he served in academic and administrative positions at Washington State University, Mississippi State University, and the University of Kentucky. He is a fellow of the American Society of Mechanical Engineers.

Ross B. Corotis (Vice Chair) is Denver Business Challenge Professor, Department of Civil, Environmental, and Architectural Engineering, at the University of Colorado at Boulder. He has a background in structural mechanics and stochastic vibrations, and his primary research interests are in the application of probabilistic concepts to civil engineering problems, including wind characteristics and mesoscale storm modeling. He is a fellow of the American Society of Civil Engineers and a member of the National Academy of Engineering.

Panel for Information Technology

Albert M. Erisman (Chair) is the codirector of the Institute for Business, Technology, and Ethics. He recently retired from the Boeing Company, where he was director of mathematics and computing technology and a Boeing senior technical fellow. At Boeing, he led a staff of 250 computer scientists, mathematicians, statisticians, and engineers who provided leadership for Boeing in all areas of information technology and mathematics. He holds a B.S. in mathematics from Northern Illinois University and an M.S. and a Ph.D. in applied mathematics from Iowa State University. His own research has been in mathematical algorithms, mathematical software, and the applications of these to the improvement of Boeing engineering and analysis codes. His recent responsibilities include addressing the broader area of the application of advanced information technology to the transformation of business processes. His management focus has included the linking of research and development with business requirements, and the delivery of technology for business benefit. He served as a member of the National Research Council's Committee on Information Technology Research in a Competitive World.

C. William Gear (Vice Chair) is president emeritus of the NEC Research Institute. Prior to joining NEC, he was head of the Department of Computer Science and professor of computer science and applied mathematics at the University of Illinois at Urbana-Champaign. His research expertise is in numerical analysis and computational software. He received a B.A. and an M.A. in mathematics from Cambridge and an M.S. and Ph.D. in mathematics from the University of Illinois at Urbana-Champaign. He is a member of the National Academy of Engineering and a fellow of the American Academy of Arts and Sciences, the Institute of Electrical and Electronics Engineers, the American Association for the Advancement of Science, and the Association for Computing Machinery. He served as president of the Society for Industrial and Applied Mathematics. He is past chair of the NRC Army Research Laboratory Technical Assessment Board and served on the NRC Committee on Future Environments for the National Institute of Standards and Technology.