An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2002

National Research Council

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

FISCAL YEAR 2002

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Division on Engineering and Physical Sciences
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Preface

This assessment of the technical quality and relevance of the programs of the Measurement and Standards Laboratories of the National Institute of Standards and Technology is the work of the 165 members of the National Research Council's (NRC's) Board on Assessment of NIST Programs and its panels. These individuals were chosen by the NRC for their technical expertise, their practical experience in running research programs, and their knowledge of industry's needs in basic measurements and standards. Each has given of his or her time without remuneration to participate in this assessment process.

I am continually impressed with the amount of time and energy that these review participants are willing to give to this assessment process. These individuals have taken fully six to seven days away from their jobs, on average, to participate in this assessment. Their willingness to do so speaks to the importance they attach to the NIST mission and to their commitment to the idea of striving for improved performance through performance measurement. I wish to thank the expert members of the Board and panels for their participation in and dedication to this process. Without their willingness to contribute their time and expertise, NIST would be deprived of a valuable management tool.

I am also impressed with the responsiveness of NIST to the findings of the Board and its panels. Most NIST managers and scientists have treated the assessment process as an opportunity to gain fresh insight into their programs and customers and have modified their plans and programs according to these insights. It is reassuring to see a federal agency so committed to program excellence and responsiveness to customer needs. The success of this assessment is dependent upon NIST cooperation and receptiveness to the inquiries and activities of the Board and panels. We thank NIST staff for the time spent in meeting with Board and panel members, as well as the time spent in preparing background information for them.

In carrying out this assessment, the Board and panels sought to meet the specific charge given by NIST and reproduced in Appendix A. Briefly, this charge calls for the Board and panels to address:

- The technical merit of the laboratory programs relative to the state of the art worldwide;

- The effectiveness with which the laboratory programs are carried out and the results disseminated to their customers;
- The relevance of the laboratory programs to the needs of their customers; and
- The ability of the laboratories' facilities, equipment, and human resources to enable the laboratories to fulfill their mission and meet their customers' needs.

I hope that the readers of this report find it to be fully responsive to the charge and that those with responsibility for oversight of NIST programs will regard this report as a useful tool in efforts to continually improve the programs of that respected institution.

Linda Capuano, *Chair*
Board on Assessment of NIST Programs

Acknowledgment of Reviewers

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 Bennett, International SEMATECH and Texas Instruments,
Eric F. Burnett, Pennsylvania State University,
Radford Byerly, Jr., Boulder, Colorado,
Francois J. Castaing, Castaing & Associates,
Josephine Cheng, IBM Santa Teresa Laboratory,
Gregory R. Choppin, Florida State University,
Uma Chowdhry, DuPont Company,
Marc D. Donohue, Johns Hopkins University,
David A. Dornfeld, University of California, Berkeley,
William Eddy, Carnegie Mellon University,
Richard J. Farris, University of Massachusetts,
Placid M. Ferreira, University of Illinois at Urbana-Champaign,
John Fishell, U.S. Navy,
John W. Fisher, Lehigh University,
David W. Green, Albion College,
James C. Holste, Texas A&M University,
Larry J. Howell, General Motors (retired),
James U. Lemke, Recording Physics, Inc.,

J. David Litster, Massachusetts Institute of Technology,
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Rose A. Ryntz, Visteon Automotive Systems,
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Rao R. Tummala, Georgia Institute of Technology,
James Waldo, Sun Microsystems,
Ronald L. Walsworth, Harvard-Smithsonian Center for Astrophysics, 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, 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 committee and the institution.

Contents

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The State of the Laboratories

This volume is the product of a process of assessment that began in December 2001 and ended with the finalization of this report. The Board on Assessment of NIST Programs met twice in fiscal year 2002; the agendas of those meetings are reproduced in Appendix B. The meetings gave the Board an opportunity to receive briefings and have discussions with National Institute of Standards and Technology (NIST) managers and to deliberate and reach findings in executive sessions. In addition to information obtained from these meetings, this report is also based on the reports of the seven major panels and one ad hoc panel operating under the Board. Each panel met with the managers and staff of the NIST Measurement and Standards Laboratories (MSL). Prior to those meetings, subgroups of the panels had spent 1 to 2 days reviewing in detail ongoing programs in their areas of expertise.

This chapter represents the Board's judgments regarding the overall state of the NIST MSL. It offers findings that the Board hopes can be used to further increase the merit and impact of NIST MSL programs. Chapters 2 through 8 offer in-depth reviews of each of the seven laboratories of the MSL and provide findings aimed at their specific programmatic areas. Chapter 9 reviews MSL programs in one technical area (measurement services) that spans the NIST organizational structure. Appendixes C and D give information on NIST functions and organization, respectively. The acronyms and abbreviations used in this report are defined in Appendix E.

This chapter reflects the Board's assessment of the general state of the seven NIST Measurement and Standards Laboratories as a whole, and it presents issues that are common across the laboratories. The Board's assessment is divided into three sections: Technical Merit of Laboratory Programs, Program Relevance and Effectiveness, and Impact of Resources on Technical Programs. These sections provide the basis for the following observations:

- Overall the technical merit of the laboratories' work remains high, with instances of work that is outstanding in its excellence.
- The breadth and depth of the laboratories' technical talent allow NIST to respond to customer needs, whether anticipated or unanticipated.

- NIST's responsiveness was demonstrated in its ability to direct resources to technical investigations required by the terrorist attacks of fall 2001.
- Strategic planning across the laboratories is in various stages of maturity. While use of strategic planning at NIST continues to mature, there is still significant room for improvement overall.
- Better resource planning, particularly planning for human resources and equipment, is required to ensure that the laboratories have the skills and equipment needed to meet future customer needs. Resource planning needs to be tied to strategic planning.
- NIST's newly defined Strategic Focus Areas (SFAs) represent a solid basis for NIST-wide strategic planning. Some of the SFAs require better definition and must be more aggressively pursued to achieve the critical mass necessary to have an impact in these areas.

TECHNICAL MERIT OF LABORATORY PROGRAMS

Each of the seven panels assessing the individual Measurement and Standards Laboratories found that the technical quality of the ongoing work remains quite high overall. In addition, each laboratory had instances of work that was outstanding in its excellence, in its creativity, or in the level of technical skill demonstrated. Each of the seven laboratory reviews in Chapters 2 through 8 cites examples of outstanding technical merit. Several such examples are highlighted here.

- In the past year, NIST researchers passed a major milestone in the drive to further improve the accuracy and stability of fundamental frequency standards. Frequency standards have long been based on atomic transitions in the microwave region of the electromagnetic spectrum. Measurements of transitions at optical frequencies are more stable than measurements of microwave transitions; however, it is not possible to do as precise a cycle count of optical transitions as of microwave transitions, a necessary condition for making high-precision clocks. NIST scientists demonstrated a frequency standard based on an optical transition in mercury 199, using frequency combs to translate the optical frequency into a microwave output for cycle counting.[1] This standard has already demonstrated frequency stability on the order of 10^{15} and has the potential to achieve uncertainties better by a factor of 1,000 than current frequency standards. This work made world headlines in 2001.[2]
- NIST researchers have demonstrated the use of nanoscale "quantum dots" composed of indium arsenide as single-photon detectors. Existing staff expertise in single-electron counting was used to couple an electrometer to these quantum dots, generating a single-electron electrical signal with each single-photon event. This technical tour de force has the potential for significant use in quantum computation and communications research.
- NIST researchers are developing new gas pressure standards that are based on measurements of the dielectric constant of helium rather than on the current dead-weight methods. The new method will reduce the uncertainty of intercomparisons of pressure measurements. NIST has demonstrated the new method to within a factor of 10 of the currently accepted pressure-sensing uncertainty standard.

[1]Diddams, S.A., et al., "An Optical Clock Based on a Single Trapped 199Hg+ Ion," *Science* 293, 825-829, 2001.
[2]Chang, K., "A New Atomic Clock May Push Precision to the Next Level," *New York Times,* July 31, page F4, column 2, 2001. See also <abcnews.go.com/sections/scitech/CuttingEdge/opticalclock010713.html>.

Finally, although this honor was for work performed several years ago, the Board must note the awarding of the 2001 Nobel Prize in Physics to NIST researcher Eric Cornell and his collaborator Carl Wieman of the University of Colorado. Cornell and Wieman shared the prize with Wolfgang Ketterle of the Massachusetts Institute of Technology. The prize was awarded for their demonstration of Bose-Einstein condensation, a long-predicted state of matter never before seen in the laboratory. This discovery has opened up new avenues in basic physics and holds the potential for application to improved frequency standards and atomic clocks (both basic to NIST's mission to keep and disseminate basic standards of measurement such as time) and to quantum computation.

PROGRAM RELEVANCE AND EFFECTIVENESS

Examples of Program Responsiveness

The underpinning of the relevance and effectiveness of the laboratories' programs is their technical excellence and technical innovation. The laboratories generally maintain a good balance between excellent basic research and efforts directed at specific customer applications. This balance enables the laboratories to maintain a long-term perspective while addressing current needs. The quality of its programs enables NIST to attract and retain a high-quality technical staff. The breadth and depth of this talent provide the laboratories with the flexibility required to respond to both known and unanticipated needs.

Many examples could be cited that show how NIST can respond quickly to unanticipated customer needs. Because of their particular importance, the Board highlights several outstanding examples of NIST responsiveness to the terrorist attacks in the fall of 2001.

- With support from the National Institute of Justice and in collaboration with university researchers, NIST has for several years maintained a program in the development of DNA forensics tools and standards. NIST researchers had made substantial progress in developing mass spectroscopic measurements for performing short tandem repeat DNA typing on DNA samples of lengths shorter than those that can be probed by existing methods. The ability to utilize shorter and shorter lengths of DNA sample enhances the chances of achieving an identification based on a degraded DNA sample. In response to a request from the New York City Medical Examiner's Office, NIST quickly developed and supplied assay kits based on its latest research for use in forensics laboratories involved in identifying the remains of victims of the World Trade Center attack.
- As part of its ongoing research in building safety, NIST has developed computer programs to simulate the flow of smoke and other contaminants through building ventilation systems. Owing to this expertise, NIST staff were called upon to model the likely routes of anthrax dispersal after this biological agent was released in the Hart Senate Office Building in Washington, D.C. NIST researchers helped to determine the sites of potentially greatest contamination and the most likely means of dispersal, which played a role in the design and implementation of the decontamination process. Because a model of the building did not already exist and because access to the building was limited, researchers had to make many assumptions in order to create a model of the ventilation systems that could be used with the group's contaminant flow prediction tools. However, despite these constraints, the project was successful and demonstrated the importance of this type of analysis.
- NIST has long maintained expertise in quantifying radiation doses. A major customer for this work is the medical industry, which uses NIST measurement techniques, standards, and services to ensure that patients receive the proper dose of ionizing radiation used for medical purposes, such as

x rays and gamma rays. This expertise found another application in response to the presence of anthrax in federal mail. NIST researchers quickly mobilized to test the effectiveness of electron-beam decontamination of mail, helping to design a decontamination protocol to enable resumption of mail delivery to federal sites and coordinating the interagency task force set up by the White House to address this problem.

Strategic Planning

Across the NIST laboratories, individual projects are generally aligned with some identified customer need. In addition, NIST has begun new efforts to obtain input and feedback from its customers, for example, through its Industrial Liaison Office. The emphasis on strategic planning in many of the laboratories and the ongoing NIST-wide strategic planning process have helped raise awareness among staff members of the importance of aligning their work with identified or anticipated customer needs.

While the use of strategic planning at NIST continues to mature, significant room for improvement overall still exists. The NIST-wide strategic planning exercise has, to date, generated some important critical thinking among NIST managers about NIST's capabilities and priorities. The Board anticipates seeing further progress on NIST-wide planning and looks forward to reviewing the resulting planning document. While each of the individual laboratories has made some efforts toward strategic planning, the results are mixed. Several laboratories have gone through meaningful planning processes, have developed sound plans, and have been effectively communicating plan priorities and developing staff commitment to them. Several laboratories have made positive planning efforts involving managers but have not yet achieved the necessary levels of staff commitment at all levels to make these planning efforts meaningful tools for guiding their organization's activities. The remaining laboratories have produced documents entitled "Strategic Plan," but these documents have little relevance and seem to have been produced with cursory involvement of staff in a "check the box" exercise rather than as part of a meaningful, significant effort to determine laboratory priorities and directions.

Why is strategic planning necessary if the technical excellence of work in a laboratory remains high? Strategic planning is necessary to ensure that this technical expertise is applied to projects of the highest priority relative to institutional goals and objectives and that the maximum impact is obtained from programmatic investments. Strategic planning provides a tool for making tough program decisions under constrained resources in such a way that staff understand the rationale for and accept the decisions.

To achieve meaningful strategic planning, it is important first to realize that the process is at least as important as the final document and then to involve staff at all levels in a discussion of priorities and objectives that aims to enunciate a vision of the organization's current needs and future directions that is clearly understood throughout the organization. The written result, the strategic plan, serves only to document these discussions and can never replace them.

The Board believes that the laboratories could benefit from the sharing of best practices, particularly in strategic planning. The Board and panels saw instances of creative responses to customer needs that the Board believes could be applied more broadly. For example, the Information System in Support of Calibrations, an excellent tool for tracking calibration services, is useful both to customers, who need to know the status of their requests for service, and to service managers, who must allocate resources to meet service requests. This system could be used for all calibration services and could be adapted for use in managing other services. As another example, Recommended Practice Guides—which detail in simple terms how to properly perform basic measurements that are used commonly but not always frequently in industry—are an excellent way of disseminating NIST's measurement expertise and improving the quality and efficiency of industrial measurements. These guides have been produced for measurements of the properties of basic materials but seem ripe for expansion to other technical areas. It appears to the Board that many excellent examples of innovative project management and customer outreach could achieve broader use if more active communication took place among the laboratories on their successes and best practices.

IMPACT OF RESOURCES ON TECHNICAL PROGRAMS

Human Resources

There is no doubt that NIST's most impressive resource is its staff. The Board is continually impressed by the exceptional technical capabilities of NIST researchers, by their dedication to their work, and by the good morale generally evident throughout the institution. The Board's previous concerns about staff retention have now faded as the private sector cuts back on new hires. NIST has also been able to attract excellent researchers into its postdoctoral program, the traditional route for eventual permanent hires.

The age profile of NIST staff indicates that a significant number of retirements will occur among the technical staff in the next 5 to 10 years. The Board is concerned about loss of key skills if these retirements are not planned for. While recognizing that individual retirements cannot be predicted exactly, general personnel planning can take anticipated changes into account. These future retirements also mean that valuable potential mentors for new staff will be departing. The Board believes that NIST should act now to capture this key experience by actively promoting and utilizing a mentoring program, which should include training staff on the roles of mentors.

Facilities and Equipment

The equipment available to NIST research staff is adequate overall, but the situation is quite mixed. Some instances of outstanding, unique equipment exist—for example, in nanostructure assembly and characterization. NIST staff reported few problems or inadequacies with their equipment, but the panels noted instances—for example, in semiconductor manufacturing metrology—where instrumentation is not up to date compared with what is being used by NIST's industrial customers.

The Board has continuing concerns about facilities, particularly in Boulder, Colorado. Although some progress has been made in remediation of unacceptable conditions in Boulder, panels still report substandard conditions (see Chapters 2, 4, and 6). Some facilities are inadequate for the equipment that they house. The Board is concerned that these problems could become safety hazards. Facilities deficiencies in Gaithersburg, Maryland, continue to hamper the efficiency of work in many buildings. The Board has notified the NIST director that it wishes to perform a detailed review of facilities adequacy in its 2003 assessment.

The geographical dispersion of NIST researchers—between Gaithersburg and Boulder, and between the main Gaithersburg campus and NIST North building in Gaithersburg—has made some research interactions difficult. Management attention can improve these interactions. For example, the Materials Science and Engineering Laboratory significantly increased collaboration between its Boulder and Gaithersburg researchers by designating a small but significant travel budget that enabled collaborators to meet face-to-face. The assessment panel noted a significant improvement in both the quality and the quantity of such collaborations in the past year. Other solutions could include increased use of information technology for remote teaming, videoconferencing, teleconferencing, and so on.

NIST should manage its geographic dispersion as an opportunity to develop communication technology and flexible organizational skills.

Resources and Strategic Planning

The Board and its panels noted that strategic planning is still not mature enough throughout NIST to influence resource planning significantly. Where solid strategic plans exist, they are being used to determine current program priorities and in that sense are determining where resources are being spent. But the Board and panels did not observe the use of plans and planning for prospective resource utilization. For example, anticipated retirements mean that a significant turnover in permanent staff will be occurring, but the Board and panels did not see evidence that strategic plans were being utilized to develop personnel plans to guide hiring over the next several years. The NIST facilities plan does not yet appear to be tied to the NIST strategic planning process, and the Board and panels have seen no major equipment plan. Strategic planning should help set guidelines for managing all of these resources over the intermediate and long term.

Panels were particularly concerned with the lack of an equipment plan for the Advanced Measurement Laboratory (AML) that is currently under construction. This facility is slated for occupancy in 2004. The major equipment that will be required to take advantage of the building's capabilities generally cannot be moved readily or acquired quickly. NIST needs a plan detailing which equipment will be moved, which will require refurbishment so that it can be moved, and which will be acquired for the new building. NIST is already behind schedule on equipment planning if it wishes to take advantage of the AML's full capabilities upon occupancy.

The panels heard much discussion of the Strategic Focus Areas delineated in the NIST strategic planning process. It is clear that the importance of these SFAs is being communicated throughout the institution and that programs are being realigned (and not just relabeled) in response. This initial progress is heartening. The Board encourages NIST management to exercise continued care to ensure that these SFAs do not devolve into "buzzwords" but remain a meaningful tool for guiding the focus of NIST programs.

There is a need for NIST to define some SFA programs better and to pursue them more aggressively. For example, the homeland security SFA has some funding and draws on ongoing programs, but significantly more opportunity exists for NIST in this area. Some of the laboratories with significant homeland security activities need to market their capabilities more aggressively in order to take advantage of the current opportunity to have an impact in this area. In biotechnology, a significant U.S. industry already exists, whereas the NIST effort is more appropriate to a fledgling technology sector. The biotechnology SFA needs greater focus and definition, and the overall program must grow if NIST is to have a significant impact in this area. In nanotechnology, NIST has world-leading researchers on its staff and has a large role to play in developing critical nanoscale measurement techniques and standards. For example, nanoscale measurement standards are needed in mask dimensional metrology and optical CD standards for semiconductor manufacturers (see Chapter 3). A major federal initiative doubled U.S. federal spending in this area in 2001, to almost $500 million total, but NIST garnered only $2 million of that increase.

MAJOR OBSERVATIONS OF THE PANELS

In addition to comments of the Board noted above, following are the major observations of its respective assessment panels on each of the seven NIST laboratories and on NIST measurement services. These observations are discussed in Chapters 2 through 9.

Electronics and Electrical Engineering

• The work under way in the Electronics and Electrical Engineering Laboratory (EEEL) continues to be of the highest technical quality. The impact of the programs on industry and other NIST customers is significant.

• The panel is pleased with the progress that has been made on strategic planning in the laboratory over the past year. The next step will be strengthening of the links between the laboratory-level plan and the NIST-level plan, as well as between the plans at the laboratory and the division levels. Eventually, linkages to the strategic plan should be seen at the level of individual projects.

• The laboratory has clearly placed increased emphasis on interactions with NIST customers; the panel applauds this outreach effort and has seen the positive impact that these relationships have on project selection and dissemination. This work could be supplemented by adding more explicit checkpoints to project plans, thereby providing opportunities for customers to validate the appropriateness of continuing programs during the programs' execution.

• As can be seen by the difficulty of obtaining funding for new or renovated buildings in Boulder, the construction of the Advanced Measurement Laboratory at NIST Gaithersburg is a very special opportunity for NIST and EEEL. To make full and effective use of this facility, a comprehensive and unified plan for utilization of the AML is needed. This plan should take into account the types of projects that should be performed in the AML, the capabilities and equipment that NIST as a whole will need to develop or purchase for the AML, and the continuing costs of supporting and maintaining the equipment and facility.

Manufacturing Engineering Laboratory

• The panel concurs with the broadening of the Maufacturing Engineering Laboratory (MEL) mission statement to recognize manufacturing beyond that of discrete parts. MEL should consider whether its mission should state its role in information technology more explicitly and whether the mission statement should be posed in more proactive terms.

• MEL has made progress in its strategic and program planning efforts. More remains to be done to achieve an integrated plan for MEL efforts at all levels. In particular, the laboratory needs a resource plan that can be integrated with the strategic plan to ensure that MEL will have the skills, equipment, and facilities it needs to meet its intermediate-term goals and objectives.

• MEL has improved its customer focus but needs to continue to work to define its customers better. In particular, to have the impact on manufacturing that it seeks, MEL must broaden its customer focus by looking deeper into the supply chain. It should also consider customers at all levels of the companies and organizations with which it interacts, not just at the level of scientific and engineering peers.

• The panel agrees with MEL's matrix management approach as a means to best utilize staff skills to accomplish laboratory objectives. Changes in the employee evaluation process may be necessary to better align evaluation with the program management structure.

• The panel is concerned about the decline in the number of MEL technical staff and its impact on the laboratory's ability to meet its goals and objectives. The laboratory lacks a human resource plan that anticipates skills needed to meet goals, takes staff retirements and separations into account, and lays out a strategy to ensure that MEL has or can obtain the skills necessary to meet its highest-priority objectives. Careful consideration should also be given to the ratio of administrative support staff to technical staff and to the ratio of managers to technical staff.

Chemical Science and Technology Laboratory

- Chemical Science and Technology Laboratory (CSTL) programs continue to have high technical merit overall.
- Awareness of customer needs and customer impact is increasing at all levels of CSTL staff.
- The panel is pleased with improvements made to CSTL use of the World Wide Web. Hiring a staff member devoted to Web utilization and Web-based dissemination is a positive step. A strategy is needed for Web-based dissemination, as databaÓis cur¨ ntly exist that are not kept up to date.
- CSTL needs a human resources plan that can be integrated with the CSTL strategic plan to account for the training, hiring, and succession planning needed to achieve laboratory goals and objectives.
- CSTL should utilize industrial fellowships to learn more about its customers and to quickly gain skills necessary to achieve objectives in new and emerging areas. Any plan to place a staff member in industry for an extended period must include a plan for how that person will utilize new skills upon returning to NIST. In order to attract staff participation, industrial fellowships must be tied to advancement, reward, and recognition.
- More proactive training of group leaders is required to help them achieve success in the multiple roles they are called on to fill in their positions.
- CSTL should reexamine the rationale for its decision on building a microelectromechanical systems fabrication capacity in-house. If the decision is made to go forward with an on-campus facility, a long-term plan is necessary to provide for the cost of maintaining and utilizing it.

Physics Laboratory

- The Physics Laboratory continues its tradition of technical excellence and leadership. The awarding of the 2001 Nobel Prize in Physics to one of the laboratory's staff members is the most obvious evidence of this excellence.
- The Physics Laboratory reaction to the anthrax attacks of late 2001 was outstanding for its responsiveness to unanticipated national need and for its excellent utilization of established NIST skills and resources. Staff involved in this effort are deserving of the highest praise and gratitude.
- The panel commends the leadership role that the Physics Laboratory is taking in the NIST-wide health care initiative and the strong focus that the laboratory has brought to its efforts in this area in the past year.
- 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 by the laboratory and its divisions to allocate resources, determine program prioritization, and produce enhanced program focus and effectiveness.
- The panel recommends enhanced efforts to develop interlaboratory collaborations and other partnerships that would help leverage Physics Laboratory resources while more effectively meeting NIST-wide strategic goals.

Materials Science and Engineering Laboratory

- The Materials Science and Engineering Laboratory (MSEL) continues to field programs of high technical merit and strong relevance and effectiveness.
- Laboratory managers at all levels must reinforce laboratory goals and objectives in both words

and action in order to increase understanding of these priorities throughout the laboratory and to improve program focus.

- The panel is concerned that decreasing staff levels put core MSEL competencies at risk and hamper the laboratory's ability to step up to new challenges and priorities.
- MSEL should seek further opportunities to leverage its human resources through appropriate collaborations. The Tissue Engineering Program is an excellent example of such leveraging.
- Increased staff travel between Boulder and Gaithersburg has paid off in better collaborations between the two sites. Funding for such travel should be continued.

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 (BRFL). 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.
- BFRL could increase the impact of its work by focusing on the most important strategic objectives and priorities. The laboratory has taken the first step toward the development of a strategic plan. The next steps include sharpening the vision for the future of the laboratory, developing a comprehensive set of strategies and tactics to achieve this vision, and defining clear goals and metrics for success and accountability. An outside facilitator should be utilized to assist in integrating input from laboratory staff and external customers.
- 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 laboratory has an initial outline for how it can contribute in this area. 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 associated with a large, multiorganization project, and new skills and people will be needed for this task.
- 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 be prepared to propose construction of a state-of-the-art facility for fire testing of structures under load as part of the homeland security effort and to 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 at the laboratory level is needed, as are staff expertise and time that can be devoted to the process of getting this work adopted into regulations and actual use.
- The planned merger of the Structures and the Building Materials Divisions is an opportunity for

the laboratory to build a unit that can lay the groundwork for a future in which materials are engineered to meet specific structural performance requirements. The panel is supportive of this ambitious goal but cautions that leadership and communication will be critical in combining groups with different cultures and different customers.

Information Technology Laboratory

- The panel is impressed with the progress that has occurred in strategic planning in the Information Technology Laboratory (ITL), particularly in the emergence and acceptance of a framework under which laboratory activities operate. The framework includes an ITL Research Blueprint and ITL Program/Project Selection Process and Criteria.
- ITL has done a remarkable job of becoming more customer-oriented over the past several years. The panel applauds the laboratory's efforts in outreach and notes that the progress reflects improvement in a whole range of areas, from gathering wider and more useful input to help with project selection to increased dissemination and planning for how customers will utilize NIST results and products.
- The strong customer relationships now need to be balanced by robust visibility and recognition in ITL's external peer communities. Publications in top-tier journals, presentations at high-profile conferences, and awards from ITL's peers will help confirm the technical merit of the work done at NIST and will add to the laboratory's credibility with its customers.
- Conveying awareness of the social issues related to ITL's technical work in areas such as biometrics is an important element of the credible presentation of ITL results to diverse audiences. In certain areas, considering the technical and social context of how the work will be used may help focus the research on the most appropriate questions.
- The shift of the information technology (IT) support functions to a new unit reporting directly to the NIST director is an opportunity and a challenge for NIST leadership. If this new unit can convince the NIST laboratories to embrace consistent, institutionwide standards for IT systems, it will be an important step and a major cultural shift at NIST. Appropriate emphasis is being placed on demonstrating how IT services can facilitate research and how standardizing basic applications can save time and money.
- The retirement of the current director of ITL is clearly a source of concern within the laboratory. The panel recommends that NIST leadership focus on communicating clearly with staff about the selection criteria for the director's replacement and that it supply staff with frequent updates on the progress of the search and hiring process. Sharing of relevant information will certainly help the transition proceed more smoothly.

Measurement Services

- The current system of flexible distributed management of NIST measurement services provides the capacity for positive customer relationships and responsiveness, excellent technical decision making, and structured coordination through the internal Measurement Services Advisory Group (MSAG).
- Excellent grassroots connection with the customers of measurement services is evident, and much information on customer needs is gathered through such channels. To extract maximum value from such information, a process is needed to gather and analyze it centrally and to disseminate it across NIST.
- The MSAG should develop an overall strategic plan for measurement services that is consistent with the overall NIST strategic plan being developed. This would help ensure that the services offered

are addressing the most critical customer needs and are providing those measurements that have the most leverage in the U.S. economy. The Strategic Focus Areas identified in the NIST strategic planning exercise provide a good template on which to build a measurement services strategy. The plan would also provide the basis for the needed facility and staff succession plans.

- While staff involved in measurement services receive significant feedback from their customers with respect to customer needs, the use of prospective marketing studies would help the MSAG better target those services that would have the greatest impact on U.S. competitiveness.
- Metrics for measurement services are needed to provide the MSAG with tools to assess performance and take necessary programmatic action. The panel recommends that the MSAG develop "dashboard" metrics that can also be used to give customers and staff succinct, easy-to-understand measures of NIST performance and demonstrate NIST's commitment to continual improvement in its programs and services.
- The MSAG should engage in a "best practices" exercise to propagate the use of the most effective and innovative means of identifying and meeting customer needs.
- The MSAG should expand the NIST quality system to include a statement of voluntary compliance with the ISO/IEC 17025 quality standard where applicable and appropriate to a national measurement institute.

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Electronics and Electrical Engineering Laboratory

PANEL MEMBERS

Lori S. Nye, Silicon Genesis, Inc., *Chair*
Constance J. Chang-Hasnain, University of California, Berkeley, *Vice Chair*
Thomas E. Anderson, Airtron, Division of Litton Systems, Inc.
Jerome J. Cuomo, North Carolina State University
Peter J. Delfyett, University of Central Florida
Russell D. Dupuis, University of Texas at Austin
Thomas J. Gramila, Ohio State University
Katherine L. Hall, PhotonEx Corporation
David C. Larbalestier, University of Wisconsin-Madison
Tingye Li, AT&T Research (retired)
Tso-Ping Ma, Yale University
Robert C. McDonald, Intel Corporation (retired)
Bruce Melson, GE Aircraft Engines
Terry P. Orlando, Massachusetts Institute of Technology
Ghery S. Pettit, Intel Corporation
Robert Rottmayer, Seagate Research
Douglas K. Rytting, Agilent Technologies, Inc.
Dennis E. Speliotis, ADE Technologies, Inc.
Dale J. Van Harlingen, University of Illinois at Urbana-Champaign
Ronald Waxman, University of Virginia (retired)
John A. Wehrmeyer, Eastman Kodak Company (retired)
H. Lee Willis, ABB, Inc.
Donald L. Wollesen, Advanced Micro Devices, Inc. (retired)

Submitted for the panel by its Chair, Lori S. Nye, and its Vice Chair, Constance J. Chang-Hasnain, this assessment of the fiscal year 2002 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 21-22, 2002, in Boulder, Colorado, and documents provided by the laboratory.[1]

[1]National Institute of Standards and Technology, Electronics and Electrical Engineering Laboratory, *Summary of 2001 Project Status Reports (10/1/2000–9/30/2001)*, National Institute of Standards and Technology, Gaithersburg, Md., January 29, 2002. *Programs, Activities, and Accomplishments* books for each division are available online at <http://www.eeel.nist.gov/lab_office/documents.html>.

LABORATORY-LEVEL REVIEW

Technical Merit

According to laboratory documentation, 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, which was expanded in 2000 to include the words "improve the quality of life" and to explicitly mention "measurement science and technology" and "standards," is an appropriate mission for EEEL. It is supported by a strategic plan,[2] which was revised during the past year.

For the previous assessment (fiscal year [FY] 2001), EEEL had produced a strategic plan containing a statement of vision and mission and a concise list of values. During the past year, EEEL expanded this plan to explicitly delineate the laboratory's role and the factors that enable it to meet its mission. These factors include EEEL's focus on making unique contributions; on having an impact on productivity and competitiveness; and on serving substantial industries, through which NIST technologies can have a significant economic effect. The strategic plan also explicitly acknowledges the core NIST competency in measurements and emphasizes support for measurement accuracy, accessibility, and applicability as part of EEEL's role. The plan also states that, independent of organizational structure, the laboratory's work is grouped in four major programs: Foundation for All Electrical Measurements, Electronics Industry, Electrical Industries, and Criminal Justice and Public Safety. Each program has a broad goal and a series of specific technical objectives, which are supported by the division programs and individual projects.

EEEL's revised strategic plan is consistent with its mission and is an appropriate plan for the laboratory level. The next steps will be making and strengthening the connections between the EEEL plan and the NIST-level strategic plan and between the EEEL plan and the EEEL division plans and projects. While the laboratory is responsible for determining overall directions and priorities (consistent with NIST-level goals), the divisions will be responsible for the tactical plans needed to meet these objectives. Strong, long-range divisional plans based on technology trends and a vision of the future goals and capabilities of EEEL will be very useful for supporting and guiding budgetary planning and decision making. This guidance will help the laboratory assemble the personnel, facilities, and equipment necessary to meet the future needs of customers.

The divisions are all working on strategic plans and have made varying degrees of progress. A particular highlight is the work done so far in the Electricity Division, which reorganized in order to focus more effectively on key research areas. By next year's assessment, the panel hopes that strong strategic and tactical plans will have been developed in all of the divisions, and it expects to see clear connections and coordination between the laboratory plan and these divisional plans. The panel also hopes to be able to see the impact of these laboratory and divisional plans at the project level. Ultimately, each project should be able to identify its linkage to the overall EEEL strategic plan, which in turn links to the overall NIST strategic plan.

One factor that may contribute to a strengthened connection between projects and the laboratory plan is EEEL's recent development of a series of evaluation criteria that laboratory management plans

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[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.

to use for project selection, project assessment, and resource allocation. As of February 2002, a set of draft criteria (in the three categories: fit to mission, impact, and probability of success) had been defined. The laboratory plans to begin applying these criteria to selected projects with the primary goal of testing the criteria and a secondary goal of evaluating the projects. The panel applauds the laboratory's efforts to develop a more objective and quantitative approach to choosing projects. The panel also supports the laboratory's plan to evolve the criteria after testing their effectiveness on actual projects.

The development of sound general project evaluation criteria is one important element of effective project management. Another element is that of defining key milestones with quantitative benchmarks for individual projects, as discussed in last year's report.[3] The panel saw efforts being made in this direction by some divisions, but more work still needs to be done. Determining benchmarks is easier for projects directed at meeting needs that have been explicitly (and quantitatively) laid out in industry road maps, but the value of defining clear, measurable project goals and a path to achieve them is also beneficial for projects that are not linked to predefined road maps. In addition to providing a measurement of project progress for internal evaluation, sound quantitative milestones can also be a useful outreach tool. Through the definition and dissemination of benchmarks that demonstrate progress toward and achievement of results of interest to a project's customers, the value and relevance of NIST's work can be clearly and quickly explained.

The Electronics and Electrical Engineering Laboratory is organized in six divisions and two offices: Electricity Division, Semiconductor Electronics Division (SED), 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). These units are reviewed in turn under "Divisional Reviews" below in this chapter; the OMP is included in the section on the SED.

The technical quality of the work under way in EEEL continues to be high. The panel was impressed by many of the projects it saw during the assessment. In the Electricity Division, work to exploit reductions in the size and complexity of Josephson junction arrays continues, with the goal of enabling this superior technology to be used in a portable device for the calibration of voltage standards. In the SED, work on scanning probe microscopy has helped staff identify a possible path for keeping up with the requirements of the International Technology Roadmap for Semiconductors (ITRS) in the area of two- and three-dimensional dopant profiling. In the Radio-Frequency Technology Division, the work on noise standards and measurements has resulted in the development of noise parameters for multiport amplifiers, particularly differential amplifiers, which will be critical for the increased use of differential amplifiers in cellular phones and other applications.

In the Electromagnetic Technology Division, staff have demonstrated the ability to count single photons with transition-edge bolometers. In the Optoelectronics Division, the continued development of new, robust, high-reliability wavelength standards will promote economically viable installation of wavelength-division multiplexing (WDM) communication. In the Magnetic Technology Division, the development of techniques for the in situ measurements of ferromagnetic films using microelectromechanical systems (MEMS) magnetometers has the potential to provide new and more accurate control of film processing for the data storage industry. In the OLES, NIST staff are working closely with

[3]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.

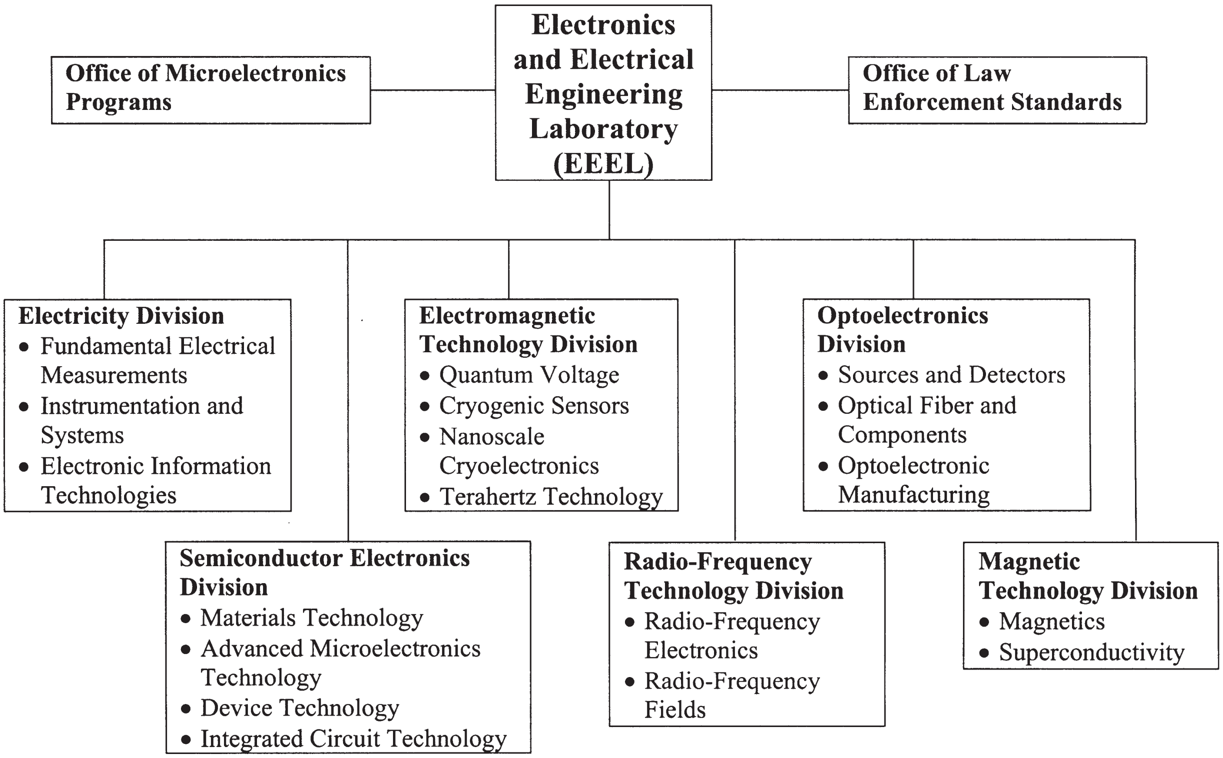

FIGURE 2.1 Organizational structure of the Electronics and Electrical Engineering Laboratory. Listed under each division are the division's groups.

the Interagency Board for Equipment Standardization and the Interoperability Working Group on standards needed by first responders in the areas of communication, detection, protection, and decontamination.

The later sections of this chapter discuss in more detail the work under way in each division. Any suggestions from the panel on maximizing the effectiveness of the individual projects are included in the respective sections.

The importance of cross-divisional and cross-laboratory collaboration continues to be appropriately recognized in EEEL. The OLES effectively utilizes relationships with other units throughout and outside of NIST to carry out a very diverse research program. In addition, SED is taking the lead on a NIST-wide competence project in the area of single-molecule measurement and manipulation. While the SED can provide key expertise in the MEMS area, the project requires a wide array of capabilities and the coordination of participants from two divisions in EEEL (Semiconductor Electronics and Magnetic Technology), two divisions in the Chemical Science and Technology Laboratory, and two divisions in the Physics Laboratory. This is an impressive example of leveraging the variety of skills available at NIST to achieve the goals of a single competency project. In the Optoelectronics Division, the panel was impressed with the leveraging of division expertise and resources through cross-divisional activities, especially in the areas of electro-optic-sampling, supercontinuum and nonlinear properties research, and quantum dot (QD) and single-photon turnstiles. In the Electromagnetic Technology Division, a programmable direct current (DC) Josephson voltage standard was transferred to the Electricity Division to be calibrated against existing standards and used in the Electronic Kilogram Project.

Program Relevance and Effectiveness

EEEL serves a wide array of customers, primarily in the electronics and electrical industries, such as electrical utilities, microelectronics companies, telecommunications and wireless industries, and opto-electronics manufacturers. Examples of the types of projects under way include work on alternating current-direct current (AC-DC) difference standards and measurement techniques to support the makers of electronic test equipment for a wide variety of industries, testing and reliability characterization of dielectric structures for the semiconductor industry, and development and dissemination of standards for the magnetic data storage industry.

The laboratory also supports other communities, including other government agencies, law enforcement, and other NIST laboratories. Examples include the work on metrology for radar cross-section systems for the U.S. Department of Defense (DOD); the active role OLES is playing in homeland security and counterterrorism programs for federal, state, and local agencies; and the transfer of the x-ray microcalorimeter technology to the NIST Chemical Science and Technology Laboratory for use in high-energy-resolution spectroscopy. More detailed discussion of the divisions' and offices' relationships with their customers is presented later in the chapter.

In the past, the panel has emphasized the importance of maintaining a close relationship with the customers and potential customers of NIST results over the course of a project. The goal of these interactions is to ensure that the project objectives meet customer needs, to provide an opportunity during the project to make any necessary changes in direction, and to ensure that an audience for the final results exists and is ready to utilize NIST's work. The panel is pleased to see more emphasis within EEEL on interacting directly with customers and on "closing the loop" (i.e., not just taking input from customers during project selection and startup, but also going back to them for comments and suggestions about ongoing or completed projects). The panel commends the laboratory for its progress in this area. However, the panel still does not see that formal checkpoints are being built into 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.

Many different measures reveal how successful EEEL has been at disseminating its results and reaching out to the many communities that benefit from the laboratory's work. In 2001, the outputs of EEEL included the following: 268 published papers, 7 conferences or workshops hosted, 262 conference talks, 2,720 calibrations performed, 365 Standard Reference Materials (SRMs) sold, and 232 instances of participation in standards committees and professional organizations (holding 66 posts). The last three measures (calibrations, SRMs, and committee participation) reflect the laboratory's commitment to "measurement science and technology" and "advancing standards," as specified in EEEL's mission, as do the wide array of measurement technology development activities throughout the laboratory.

An output measure that was not provided to the panel this year is number of patents. Patents also were not listed in the draft project evaluation criteria mentioned above (although in the deliverables section of these criteria, "technology development" is listed as a possible but rare project outcome). The panel is not taking a position on whether patents should or should not be an EEEL goal or even whether they should or should not be a measured output. However, the panel does suggest that the NIST policy in this area be clarified, as conversations with the laboratory staff revealed a range of understanding of the criteria for deciding when to apply for a patent and the process and support available for doing so. If a clear policy does exist at the NIST level, this confusion would appear to be a communications issue.

TABLE 2.1 Sources of Funding for the Electronics and Electrical Engineering Laboratory (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	33.2	32.5	34.8	36.6
Competence	1.9	2.1	2.0	2.2
ATP	1.9	1.4	2.1	2.1
Measurement Services (SRM production)	0.1	0.2	0.3	0.4
OA/NFG/CRADA	10.9	13.8	19.7	23.9
Other Reimbursable	2.7	2.8	3.2	2.7
Total	50.7	52.7	62.0	67.9
Full-time permanent staff (total)[a]	270	259	244	246

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 Electronics and Electrical Engineering Laboratory are shown in Table 2.1. As of January 2002, staffing for EEEL included 246 full-time permanent positions, of which 209 were for technical professionals. There were also 33 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

EEEL has received relatively flat Scientific and Technical Research and Services (STRS) funding over the past several years. The total budget has continued to rise, however, owing to increases in the level of external funding from other agencies (OA) sought by and awarded to the laboratory. Roughly two-thirds of the rise in OA funding predicted between FY 2001 and FY 2002 is within the Office of Law Enforcement Standards, where all funding is external, but other divisions (Radio-Frequency Technology, Electromagnetic Technology, and Magnetic Technology) also expect to see real growth in external support. This outside money can be very useful not only for supporting key programs but also for building close ties with customers in other government agencies, such as the U.S. Air Force. It is important, however, to take care that the work EEEL has done on strategic planning and project evaluation not be undermined by externally funded projects focused outside EEEL's carefully defined mission and scope. The EEEL project evaluation criteria may be a useful tool for ensuring that internal and external projects are all contributing to the laboratory's overall goals.

Another small but significant source of funding for EEEL is the revenue from SRM sales ("Measurement Services" in Table 2.1) and calibration services (included in "Other Reimbursable"). The panel recognizes that NIST is constrained by government regulations determining the fees that may be charged for these services. However, the panel notes that the fees currently being charged do not reflect the true cost of these services. If regulatory constraints preclude the adjustment of fees to more realistic levels, then the panel suggests that EEEL consider alternative ways to balance the costs and income associated with these activities. For example, certain services could be discontinued and/or transferred to commercial laboratories, or some processes could be automated to reduce ongoing costs. Similar approaches might be taken in the area of SRM production. The laboratory is clearly aware of the difficult decisions that must be made in order to balance the need to serve NIST's customers and the need to develop and provide the metrology and standards of tomorrow. In the Electricity Division's reorganization in 2001, a major focus was on improving support for the division's measurement services; one element of the division's plan is the termination of three measurement services at NIST and the transfer of those services' customers to other national laboratories in the United States and Canada. The panel supports the division's and laboratory's efforts to move forward in this area.

A consequence of the flat budgets and congressionally mandated salary increases over the past several years is a significant reduction in the total number of staff in EEEL since 1999 (down from 270 to 246). This year, several divisions reorganized their projects and/or groups. The panel notes that for all of these changes, a key factor was redistributing staff and resources to ensure that important projects and activities were supported by the technical expertise and staff time needed to meet project goals in a timely manner. These reorganizations are discussed further in the sections on the individual divisions below.

The panel applauds EEEL for recognizing the need to reevaluate the allocation of personnel resources in the current budgetary climate. However, the panel does wish to emphasize the importance of proactive planning for foreseeable changes in personnel. In some divisions, many key researchers are approaching retirement; significant areas of expertise could be lost. The panel would prefer to see more visible demonstrations that EEEL is preparing for the transitions that this change in personnel will require. Planning could address whether the laboratory should continue to work in the areas in which expertise will be lost, and, on the basis of that decision, how expertise will be transferred to existing or new staff members or how work in the affected areas will be smoothly concluded. Specific areas in which succession planning appears to be an immediate need include the Radio-Frequency Technology Division and the superconductor work in the Magnetic Technology Division.

The facilities available to EEEL continue to be an issue for the panel. The Boulder facilities in particular are substandard for the important type and quality of work being done in EEEL. Some progress has been made in a few individual cases, as in the renovation of the nanoprobe imaging laboratory in the Magnetic Technology Division and the remodeling of several large laboratories in the Electromagnetic Technology Division. However, the number of problems continues to outweigh any progress. The lack of effective buildingwide climate control limits the effectiveness of improvements in individual laboratories. For the Radio-Frequency Technology Division, this problem in Building 24 has improved marginally, but the current lack of precise environmental controls in the facility will significantly compromise NIST's ability to perform near-field antenna pattern measurements at the higher frequencies. In addition to physical problems with the facilities, the panel observed that the distribution of staff in the available space is not always optimal; the Magnetic Technology Division, with only 13 permanent staff, is spread out over five separate buildings.

As noted in last year's report, one significant improvement in Boulder in the past few years was the major renovation and expansion of the clean-room facility. The Boulder divisions, particularly the Electromagnetic Technology Division, are benefiting from access to this state-of-the-art microfabrication facility. Gaithersburg does not have this capability on-site. While several ad hoc solutions (such as having customized chips made at Sandia National Laboratories) have been effective in the short term, these approaches have depended heavily on the ability of individual researchers to form collaborative relationships with scientists who have access to appropriate equipment. The panel believes that EEEL should examine its need for the microassemblies and circuits that are increasingly critical in electrical metrology experiments and standards research, consider all the options for producing these devices, and develop a laboratory- or divisionwide strategy for efficiently satisfying the needs in both the short and long terms.

In Gaithersburg, a significant factor in future facilities planning is the Advanced Measurement Laboratory (AML), scheduled to be ready for occupation in 2004. The panel is certainly pleased that this facility is finally being constructed. The next and immediate challenge is planning for the effective utilization of the building. The panel did not see a clear, unified plan at the NIST or EEEL level for AML use. Such a plan should be completed as soon as possible and should address the questions of how decisions will be made about which projects go into the AML and what NIST's overall needs are regarding the equipment and capabilities in this building. These decisions should take into account the operating costs associated with any facilities in the AML, as well as built-in capital, overhead, and maintenance requirements. Factors worth considering would include how quickly various equipment becomes outdated and whether certain capabilities can be accessed more efficiently via collaborative relationships with other institutions. To be most effective and credible, any plans for the AML should be consistent with and closely coordinated with NIST and EEEL strategic plans.

Laboratory Responsiveness

Overall, the panel has found EEEL to be very responsive to suggestions, concerns, and questions raised in previous assessment reports. The progress on strategic planning at the laboratory level is one example, although the panel will watch for continued evolution in this area, particularly in the divisions. Examples of the divisions' commendable responsiveness to the FY 2001 report include the redirection of the compound semiconductor program in the Semiconductor Electronics Division, the stabilization of the management chain (and the resulting improvement in morale and consistency of direction) in the Electricity Division, the revision of the mission statement in the Magnetic Technology Division, the progress made on purity measurements for semiconductor gases in the Optoelectronics Division, and the delivery of standards systems to users at NIST Gaithersburg in the Electromagnetic Technology Division.

The panel is pleased with responsiveness to the assessment report observed over the past year, but has some concern about the speed and completeness of some of the responses. In general, the laboratory and divisions do acknowledge the validity of the panel's input and do discuss the issues related to any areas in which action has not occurred. In some cases, the issue may be that certain problems (such as the panel's concerns about the overall quality of the Boulder facilities) cannot be remedied at the divisional or laboratory level. However, it did not always appear that the divisions were making an effort to find alternative approaches or were effectively making their cases to higher levels of NIST management. The panel was somewhat concerned about whether this might be a problem, for example, in the case of the engineering and architectural study for a Radio-Frequency Electromagnetic-Field Metrology Laboratory (REML) facility in the Radio-Frequency Technology Division.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- The work under way in the Electronics and Electrical Engineering Laboratory continues to be of the highest technical quality. The impact of the programs on industry and other NIST customers is significant.
- The panel is pleased with the progress that has been made on strategic planning in the laboratory over the past year. The next step will be strengthening of the links between the laboratory-level plan and the NIST-level plan, as well as between the plans at the laboratory and the division levels. Eventually, linkages to the strategic plan should be seen at the level of individual projects.
- The laboratory has clearly placed increased emphasis on interactions with NIST customers; the panel applauds this outreach effort and has seen the positive impact that these relationships have on project selection and dissemination. This work could be supplemented by adding more explicit checkpoints to project plans, thereby providing opportunities for customers to validate the appropriateness of continuing programs during the programs' execution.
- As can be seen by the difficulty of obtaining funding for new or renovated buildings in Boulder, the construction of the Advanced Measurement Laboratory at NIST Gaithersburg is a very special opportunity for NIST and EEEL. To make full and effective use of this facility, a comprehensive and unified plan for utilization of the AML is needed. This plan should take into account the types of projects that should be performed in the AML, the capabilities and equipment that NIST as a whole will need to develop or purchase for the AML, and the continuing costs of supporting and maintaining the equipment and facility.

DIVISIONAL REVIEWS

Electricity Division

Technical Merit

The mission of the Electricity Division is to provide the world's most technically advanced and fundamentally sound basis for all electrical measurements and associated standards in the United States. The Electricity Division's programs involve three principle elements: (1) realizing the international system (SI) of electrical units; (2) developing improved measurement methods and calibration services; and (3) supporting the measurements and standard infrastructure needed by U.S. industry to develop new products, ensure quality, and compete economically in the world's markets. The division is organized in three groups: Instrumentation and Systems, Fundamental Electrical Measurements, and Electronic Information Technologies.

The impact of documentary standards has become much more visible in a world of expanding international trade. NIST participation in these activities is of vital importance to U.S. interests. The mission statement does not adequately reflect the division's documentary standards effort.

The level of both technical skill and design creativity for the Electronic Kilogram project is exceptionally high. The watt-balance is an exceedingly difficult apparatus to make and refine. The capabilities of the people working on this effort rise to the need. 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. This is the sort of measurement system of which NIST can be proud. This project is clearly a leader among various efforts in the world to replace the artifactual kilogram.

Historically NIST has been one of the world's leaders in the determination of the volt, and it remains so today. The leading voltage laboratories of the world today derive their value of the volt through the use of the Josephson junction devices that NIST was instrumental in developing. The staff of the Voltage Metrology project have not been resting on these laurels. Realizing the value of the Josephson-array device, they have continued to refine it and to reduce its size and complexity so that it can be portable. The need for this effort became apparent during recent interlaboratory comparison (ILC) programs for the comparison of the volt. These programs demonstrated that the predominant contributor to the uncertainty was the instability and noise of the zener diode transfer devices. It is expected that using a portable Josephson array in place of the zener diode transfer standards would improve the uncertainty of these ILCs by a factor of 10. In addition to the use of a portable Josephson-array device for ILC work, the Voltage Metrology project is moving toward the use of a programmable array for the voltage calibration services provided to its customers. EEEL enjoys a steady demand for calibration of saturated cell voltage standards from its customers. 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 certain unpredictable noise characteristics, which diminish their value as a highly stable voltage standard. The programmable Josephson array is expected to provide more accurate and efficient service.

The researchers involved in the Single Electron Tunneling project have demonstrated a considerable level of technical skill and insight into what is probably the most important challenge to the success of this general approach. The project seeks to develop a stable, manufacturable capacitance standard based on single-electron transistors (SETs) and to use this standard to "close the metrology triangle" of current, voltage, and resistance. Researchers recognized that the long-term stability of the intrinsic properties of the SETs themselves is a serious limitation on further development of this general approach to current standards. A significant effort has been undertaken to develop methods to avoid the fundamental materials problems that are at the heart of this instability. An important element of the success achieved to date lies in the ability of the principal investigator to forge collaborations with other efforts inside and outside NIST. Effective collaboration with NIST Boulder, work with a Japanese group, and work with investigators at the University of Maryland have all proven effective. The limited level of staffing for this project makes these collaborations all the more critical.

Maintaining the legal units such as the ohm is at the heart of the NIST charter. Realizing and disseminating the value of the ohm is an essential component in the foundation of international trade. 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 currently manufactured by NIST. However, these devices degrade over time, and NIST has had to work diligently to ensure an adequate supply. The level of resistance 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 project 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. Important work on high-resistance measurement capability is moving forward and will be of great value to the materials industries. In recent years, EEEL has made major improvements of measurements in the range 10 megohms to 100 teraohms. An active-arm bridge, which will cover this resistance range, is under development. A 1-teraohm standard is complete. New Hamon Transfer Standards are being developed to more accurately scale up to this range. In addition, the ability to measure resistance to 1 megohm and above is being improved through the development of a cryogenic current comparator.

The AC-DC Difference Standards and Measurement Techniques project is excellent from every perspective. Despite the simplicity of the concept, it is not simple to achieve exact AC-DC comparison and to maintain small measurement margins over a wide range of frequency and current levels; the process is subject to a host of possible sources of error and ambiguity. The division handles these difficulties in stride and makes the work look straightforward. This project has well-identified goals, a clear long-term concept of its direction and priorities, and a clear implementation plan to meet those priorities. Its members have excellent dialogue and both collegial and working relationships with similar projects at other laboratories and in other countries. The program's calibration services are highly utilized, and to all appearances they are handled in a manner completely satisfactory to its customers. It produces quality, current publications and has a high degree of internal involvement with other NIST projects.

The Realization of the SI Farad and Ohm project maintains and disseminates the farad and ohm. It is performing work to tie the U.S. legal farad to the SI. It provides the U.S. industrial base with consistent, reproducible, reliable, and traceable electrical measurement calibration in these areas.

The Realization of the SI Farad and Ohm project merits recognition for maintenance of the farad and ohm standards. This may not be as innovative or exciting as other work in the division, but it is important and fundamental to NIST's role. The project has two particularly innovative areas of technical focus—that of the calculable capacitor and research on using QH resistance for AC measurements. Both studies have well-developed research plans and show originality in concepts, implementation, and interpretation. The staff is of the highest caliber and is very committed to this work. However, the projected pace of these plans may be somewhat ambitious, given current staffing. Current trends in miniaturization of electronic equipment could create a need for ever-finer measurement of the farad and ohm, challenging this project to keep pace.

The Infrastructure for Integrated Electronic Design and Manufacturing (IIEDM) project seeks to develop a standardized means to represent electrical and mechanical manufacturing data. The manufacturing infrastructure depends on such standard representations and libraries of component parts. At present, many such libraries and data representations exist, but with no single standard. The NIST project is attempting to address many aspects of this problem, to which NIST researchers have the knowledge base to contribute solutions. In the past year, the team demonstrated one example of the use of an infrastructure to create an electronic part.

The Metrology for Electric Power Systems Program is excellent from every perspective. It has well-identified goals, clear direction and priorities, and a sound plan to meet its targets. Project professionals, technicians, and their management have developed impressive ties to and working relationships with industry, professional associations, and standards bodies associated with the use of this project's standards and services. The project members have published a number of noteworthy papers making substantial contributions to electric power metrology, and their work is well respected by the industry. Development programs such as the automated test system for power and energy, the prototype transformer efficiency measuring system, and the harmonics work all show careful planning, attention to detail in implementation, and all the expected results of good management. The project's members have excellent relationships with similar projects at other laboratories and in other countries.

The Waveform Acquisition Devices and Standards project exists to expand and improve present NIST time domain waveform measurements services. Operating at frequencies from DC to 50 GHz, these services support high-performance samplers and digitizers, and fast pulse and impulse sources. The work of this project clearly lies at the limit of what is achievable with current instrumentation. The personnel in the project have been able to develop methods that have permitted calibration of a commercially available instrument to such accuracy 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.

The Flat Panel Display Metrology project responds to the need to characterize displays quantitatively. This emphasis was selected because of the growing use of this type of display in the computer and automobile industries and in other applications. Work originally focused on the development of a robust device that could be used for ILCs and could thereby help industry narrow the disparity of measurement results. A new, more compact, robust, and transportable device is being developed for this purpose. As part of this effort, new devices were developed such as the stray light elimination tube, a baffled cylinder to reduce stray light entering the viewing detector. Some of the most important products from this project are documentary standards. Among many others, a standard entitled “Flat Panel Display Measurements Standard, Version 2.0” was published in 2001 as a Video Electronics Standards Association (VESA) document, illustrating the close working relationship EEEL has established with this industry. The project is now starting to tackle problems such as speckle in rear projection systems and near-eye display measurements. This work is expected to result in additional VESA standards for measurement.

Program Relevance and Effectiveness

The Electronic Kilogram project exemplifies the division’s ability to meet traditional objectives using modern approaches. The unit of mass is currently based on a physical artifact whose copies differ by non-negligible amounts. Numerous national measurement institutes (NMIs) are making efforts to replace these artifacts with standards based on a fundamental property of nature. The program at NIST is among the forefront of such efforts and is necessary in order that the United States retain a leadership role in the field of standards.

The AC-DC Difference Standards and Measurement Techniques project provides U.S. industry with a link between DC and AC electrical standards and maintains and improves national standards of measuring DC and AC differences, which are used to provide calibrations for scientific and industrial applications. The importance of this project is indicated by the substantial amount of calibration work requested and by requests for extensions of calibration capabilities to higher frequencies and electrical current levels. 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 shunts. These needs vary widely in terms of both the frequencies and the amounts of current involved—thus the need for standards and calibration services covering a wide range of frequency and current. Although the assessment panel has not made any specific study of present and future needs in this area, the panel’s familiarity with industry trends in general suggests that the present demand for wider bandwidth and higher current in AC-DC measurements will continue. The need for high frequencies ($>10^5$ Hz) and high current (>50 A) in combination will probably continue as a host of new monitoring, communications, and high-frequency power technologies continue to develop.

The farad and ohm are basic electrical units, and maintaining dependable, consistent, and traceable standards for them must continue to be a core priority for the Electricity Division. In addition, relating the U.S. legal farad and ohm to international standards is important for international trade, and extending their measurement to smaller levels of uncertainty is a key to technological progress in the continued miniaturization of electrical equipment.

The electric power industry depends on the Metrology for Electric Power Systems Program for calibration services in high-voltage, high-current power and energy. Electric power is so fundamental to the U.S. economy and the power industry is so dependent on accurate measurement of power flow and voltages in its systems that there is no question about the necessity of this program. The Electricity Division is meeting industry needs and maintaining its standing in international standards. Very relevant work is being carried out in many areas. Two areas of major importance are the measurement of efficiency in power distribution transformers and methods to sample and characterize harmonic power. Both are important to the electric power industry, but NIST may be underestimating the importance and relevance of the latter activities to the consumer appliance and electronics industry.

The stated objective of the Infrastructure for Integrated Electronic Design and Manufacturing project is to contribute actively to the technical development of neutral product data exchange specifications and component information infrastructure for the electronics industry. The project has two primary focus areas: Electronic Commerce of Component Information (ECCI) and Internet Commerce for Manufacturing (ICM). The NIST ECCI and ICM focus areas within the IIEDM project are recognized by a broad-based electronic industry as extremely important. Producers of electronic components, users of electronic components to produce larger subassemblies and consumer products, and developers and producers of software to aid electronic component producers in the development of their products all need to be able to communicate the critical component parameters that are contained in component information databases. Standards for describing component information and standard formats to store such information will have a significant positive impact on reducing the cost of doing business. The IIEDM addresses such information standards. Numerous standards groups meet frequently to reach agreement in these areas, which illustrates the work's importance. Standards group meetings sponsored by the Electronics Industry Alliance (EIA) and the IEEE as well as many industry ad hoc standards groups are well attended by industry representatives. The NIST scientists attend these meetings as often as possible, but their personnel resources are too limited for them to accomplish what is needed at such meetings. However, their participation is welcomed and encouraged by industry because of the neutrality and technical skills they bring to the standardization efforts. The IIEDM project is recognized by industry groups as having an important impact, but it is below a critical mass to effectively meet industry needs.

The Information System to Support Calibrations project seeks to develop and refine a workflow application to enable the automatic tracking of technical and administrative calibration information. The tracking system should reduce the percentage of time NIST scientists spend on producing the necessary calibration forms and associated reports. This project resulted from an ad hoc effort of a few dedicated and enthusiastic researchers in the Electricity Division who saw the need for an information system to meet the needs of EEEL for tracking its many calibration programs. The work is now in use for calibrations throughout all of NIST. The Information System to Support Calibrations project is another example of the dedication and enthusiasm shown by these researchers in meeting their customers' needs. Ad hoc work has now been started on a bibliographic database, which is needed because papers being written throughout NIST are listed in various databases within NIST, and searches are done with difficulty because of the diverse sources of information. The bibliographic database is intended as a consistent database within EEEL for paper searches. The work on it is approximately 50 percent complete.

Division Resources

Funding sources for the Electricity Division are shown in Table 2.2. As of January 2002, staffing for the division included 52 full-time permanent positions, of which 48 were for technical professionals.

TABLE 2.2 Sources of Funding for the Electricity Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	7.8	7.6	7.8	7.8
Competence	0.9	0.5	0.4	0.3
ATP	0.3	0.2	0.2	0.0
OA/NFG/CRADA	1.3	1.7	1.7	1.8
Other Reimbursable	1.2	1.1	1.1	1.1
Total	11.5	11.1	11.3	11.0
Full-time permanent staff (total)[a]	65	63	57	52

NOTE: Sources of funding are as described in the note accompanying Table 2.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

There were also 9 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The division reorganization plan—reducing the number of managers and groups from four to three, assigning senior professionals across two or more projects in order to assure some redundant knowledge, and flexible staffing assignments to projects—is a very innovative and skillfully executed plan to deal well with the decreasing technical resource base within the division. It appears to have met all its goals and to have enabled the Electricity Division to meet its essential mission goals and short-term targets in a satisfactory manner. Morale among professionals, technicians, and managers has improved compared with that of a year ago. The staff's commitment to their work remains at an extraordinarily high level, but many more staff members now seem to have faith in their abilities and in their division's future and to enjoy being at work.

However, the panel remains concerned about three long-term trends: (1) the gradual reduction in the number of professional staff, particularly if counted in years of experience; (2) flat budgets that do not even track inflation; and (3) swelling overhead costs. These trends cause concern about the division's long-term prospects to remain world-class in electricity metrology and to satisfy U.S. industry needs for traceable electrical standards and for calibration services based on them.

Staffing for basic measurements and services such as the volt, ohm, and AC-DC difference standards is at a marginal level. The panel was surprised that the division has been able to maintain its level of service with the current staffing level.

The IIEDM project is below critical mass. Morale is being affected. Though the project team is dedicated and highly enthusiastic, team members feel that they are lacking the resources to do their jobs well. NIST does not appear to have a plan to remedy the problems of this industrially important project.

Staffing is the central limitation on the progress of the Single Electron Tunneling project. Some effort has been made to improve staffing levels; however, the investigator added to the program has taken on other duties because of unanticipated departures in the division, and the project is once again at minimum staffing level. The panel recognizes that staffing levels throughout the division are stretched dangerously thin, making additional staffing for this project difficult. Also, limitations in clean-room processing capabilities at NIST are a concern with this project.

The Voltage Metrology project has had a steady workload supported by a small staff of fixed size. The panel has been concerned with contingency staffing for this important project. The staff is now working hard to address this concern through cross-training. No extra capacity exists in this group if any new projects need to be addressed. To keep the current workload under control, opportunities have been sought to delegate work to other organizations where appropriate and possible. The division should be commended as it continues to look for creative ways to manage its workload. For some time the Voltage Metrology project has been plagued by the lack of reliable and clean electric power, which is essential for the services it provides. A single, reliable, backup power generator has been installed to solve this problem.

The Metrology for Electric Power Systems Program has little margin to absorb any unexpected reduction in staffing, full- or part-time, without some impact on its performance. Management may wish to consider maintaining flexibility in redundant expert knowledge and skills that would allow it to quickly expand this group if the need arises. Currently, a high level of attention is being paid by the public and Congress to the electric power industry. This is certain to continue, with the growing need for accurate tracking and accounting of power, energy, and power quality on a transactional basis in the deregulated utility industry. The demand for this group's services could grow substantially over the next few years.

The researchers in the Waveform Acquisition Devices and Standards project struggle to acquire needed equipment that can be rather expensive. While current optical communications techniques require 50-GHz electrical measurements, devices are being developed in industry that are expected to reach frequencies approaching 200 GHz—well beyond current NIST's capabilities—and this need will have to be addressed at some point. Collaborations with other divisions or laboratories that have optical expertise should be encouraged and supported.

All employees should have the opportunity to enhance or broaden their skill base. Such opportunities do exist at NIST, but division employees do not seem to utilize them. As new technical needs unfold, employees should be given the opportunity to retrain with the new skills required. This should have a positive effect on the morale of employees. Division managers need to encourage the use of training programs.

Semiconductor Electronics Division

Technical Merit

The mission of the Semiconductor Electronics Division is to provide leadership in developing the semiconductor measurement infrastructure essential to improving U.S. economic competitiveness by providing necessary measurements, physical standards, and supporting data and technology; associated generic technology; and fundamental research results to industry, government, and academia. The primary focus is on mainstream silicon CMOS (complementary metal-oxide semiconductor) technology. The division's programs also respond to industry measurement needs related to microelectromechanical systems, power electronics, and compound semiconductors. The division was reorganized into four groups last year: Materials Technology, Advanced Microelectronics Technology, Device Technology, and Integrated Circuit Technology.

Division staff members have an excellent understanding of the problems facing the semiconductor industry and of those to which their unique skills can be most effectively applied. Industry views the division's contributions as unique and essential to efficiently providing measurement techniques and standards. NIST is seen as an unbiased source of measurement methods and standards, which is extremely beneficial to the industry. No other institution can provide this unique combination of skills and objectivity.

The panel continues to be impressed with the technical quality of the programs that are under way within the Semiconductor Electronics Division. The quality of the staff is the key driver of the quality of the research, and the panel notes that the accomplishments of division personnel have been recognized by governmental and other organizations on many occasions. For example, in 2001, division staff members were honored with the IEEE Components Packaging and Manufacturing Technology Society Outstanding Sustained Technical Contributions Award and the IEEE Total Excellence in Electronics Manufacturing (TEEM) Award, and two staff members were elected fellows of IEEE. The panel discusses highlights of some division programs below.

Programs in the division, although industrially driven, are engaged in the scientific research necessary to build competencies and fundamental understanding of relevant systems. Two new basic research programs have been funded in the last year and a half by the NIST Director's Competence Building Program. One of these projects, the Molecular Electronics project, initiated in 2001, has now completed the first capacitance-voltage (C-V) measurements on real molecular electronic structures. This effort is in collaboration with Hewlett-Packard, which provided the test structures. A second project, Single Molecule Manipulation and Measurement (SM^3), is targeting more accurate measurements in genomic science as its first goal.

NIST has made breakthrough progress in developing three-dimensional linewidth standards (sometimes called critical dimension, or CD, standards) called for by the International Technology Roadmap for Semiconductors. A three-dimensional standard simulates real-world measurements more accurately than current two-dimensional standards do, as actual integrated circuit (IC) structures are three-dimensional. The capability of the two-dimensional standard fell well behind industry needs a number of years ago. Technology developed by the Semiconductor Electronics Division provides linewidth measurements traceable to the atomic spacing of silicon. A 200-mm silicon wafer linewidth metrology standard was delivered to International SEMATECH in 2001. This standard permits CD measurements from 90 to 120 nm with a precision of +/–14.5 nm (3 sigma). The division expects to deliver a standard in 2002 that permits measurements in the 60- to 90-nm range with a precision of +/–7 nm (3 sigma). A commercial supplier has been qualified for volume production of the new three-dimensional standard.

The Scanning-Probe Microscope Metrology project continues to provide leadership in the application of scanning-probe microscopy to semiconductor device dopant profiling. The ITRS documents dopant profiling needs that exceed current capability. The division has developed state-of-the-art tools for these measurements. In 2001, improvements were made in two-dimensional capability, and progress was made on three-dimensional capability. The project aims to improve these measurements through better sample preparation, better use of scanning-probe techniques, and improved models for using the derived signals to generate feature profile interpretation of scanning capacitance microscopy (SCM) data. The first applications of an inversion modeling approach have successfully demonstrated the potential to improve the spatial accuracy of the technique by an order of magnitude, which will approach the accuracy called for in the ITRS. This work is crucial to the support of accurate technology computer-aided design (TCAD) device simulations in industry, which are used for the design of advanced transistors.

The goals of the Advanced Metal-Oxide Semiconductor (MOS) Device Reliability and Characterization project are to improve reliability and electrical characterization tools for advanced semiconductor technologies, with focus on ultrathin silicon dioxide and alternative gate dielectric films. While the most tangible deliverables from this project are standard test procedures and characterization techniques, researchers also conduct basic research on the reliability of advanced gate dielectrics, including ultrathin silicon oxides, oxynitrides, and high-k dielectrics. Some notable results include new understanding of the role of holes in oxide wear-out mechanisms, discovery of heavy ion-induced soft breakdown of thin gate oxides, and the initial reliability characterization of HfO_2 as an advanced CMOS gate dielectric. Use of test structures and test methods developed by NIST in response to industry need is common throughout the semiconductor industry, and NIST's transistor gate oxide metrology has kept pace with the ITRS needs. Foreign standards organizations and manufacturers have adopted U.S. standards as well.

The Thin Film Process Metrology project focuses on the characterization of candidate advanced gate dielectric materials for CMOS technology, including oxynitrides, high-k metal oxides, and metal-silicates. The division is developing optical data, optical models, and thin-film measurement capabilities to support key ITRS needs. These data and methods directly address industry needs for new dielectric development and process control. It is the only program in the world that focuses on optical measurements and modeling for gate dielectric materials and their related process metrology issues from the infrared to vacuum ultraviolet (VUV). Notable accomplishments for FY 2001 include the development and transfer to International SEMATECH of a generalized Tauc-Lorentz optical dispersion model to determine film thickness and optical properties of high-k dielectrics, the completion of sample exchange with VLSI Standards, Inc., in order to establish traceability for Si_3N_4 standards, benchmarking of a suite of one-dimensional quantum mechnical software for MOS gate C-V characterization down to 1 nm oxide thickness and expanded capability for comparison with two-dimensional software, and the installation of a VUV ellipsometer to extend NIST capability to the 8.5- to 9-eV range. This work is timely, and the measurement methodologies developed for spectroscopic ellipsometry and the comparison of C-V characterization models are highly relevant to industry needs. The software package developed for extracting the thickness distributions and dielectric constants of multilayer dielectric stacks appears powerful and is already being disseminated to industry users.

The Metrology for Simulation and Computer Aided Design project focuses on developing efficient and reliable tools and methodologies that address industry needs for semiconductor computer-aided design (CAD) and system-on-a-chip methodologies. The project is intended to develop unique test and measurement techniques to aid in the development, characterization, and validation of new and emerging device technologies. Key accomplishments in 2001 include the development of a unique characterization tool that enables the measurement of critical performance parameters of silicon carbide power Schottky diodes and silicon carbide power metal-oxide semiconductor field-effect transistors (MOSFETS). This tool provides a state-of-the-art capability that enables measurement of silicon carbide diode switching characteristics while operating at a current, voltage, and frequency close to the failure point of the device. This tool should aid industry researchers in understanding device failure mechanisms and lead to improvements in device design. In addition, transient thermal image metrology, a measurement tool developed in the division, is being used to understand thermal management in the packaging of silicon and silicon carbide power devices. This tool could potentially be used to image and calibrate the microelectromechanical systems (MEMS) that are used to characterize wire-bonding processes. Both of these tools have the potential for development into commercial systems and could be used by industry to improve package design, yields, and device performance.

The panel is pleased to see the reorganization of compound semiconductor research into several focus areas more consistent with the NIST mission. One new focus area moves into newly emerging technology based on group III nitrides as semiconductors for radio-frequency (RF), optical, and power applications. The division has assembled a unique set of tools to characterize gallium nitride devices.

These have significant relevance in both DOD and commercial applications, and researchers need tools to understand the correlation between materials and device characteristics. It appears that researchers on this study will also play a significant role in the upcoming Defense Advanced Research Projects Agency (DARPA) Wide Bandgap Semiconductor Technology Initiative. NIST will serve as an unbiased independent resource to aid in the characterization and development of nitride-based RF devices and will assist DARPA in monitoring the progress of its program.

The Microelectromechanical Systems project has made good progress in the use of MEMS devices to measure stress and elasticity in the thin-film materials widely used by the semiconductor industry. In 2001, the division demonstrated a new optical vibrometer, which measures the resonant properties of microcantilever beams used in MEMS. This technique can measure the properties of cantilever beams constructed with one material, two different materials, or the sandwiches of many materials that are found in semiconductor devices. This work has substantial technical merit in improving metrology for semiconductor industry thin films; it should be readily transferable, since it has been developed using standard silicon-based technologies.

The MEMS project also developed bond pad test structures with standard process thermocouples fabricated underneath. These structures were successfully measured during thermocompression wire-bonding techniques—an industry first. The industry makes ~8 trillion wire bonds each year. This new measurement capability will allow the manufacture of wire bonds with improved reliability and will improve production throughput. The panel looks forward to seeing this capability transferred successfully to industry. The MEMS project also made good progress on microfluidic fabrication methods and measurement systems. This capability will allow the creation of filters, valves, pumps, mixers, separators, reactors, and detection devices on one chip with micron and submicron features. A new, innovative device named the convective accelerometer was developed and patented by the division. This device should reduce the cost of accelerometers for motion sensing, resulting in improved performance and reduced cost for systems that utilize these devices, such as acceleration sensors for the deployment of airbags in automobiles.

The Human Genome project is currently challenged by the accuracy of the measurement of DNA and RNA molecules. The errors in current measurement methods have resulted in an uncertainty in the number of base pairs present ranging from 30,000 to 140,000 pairs. This leads to significant discrepancies in the genetic sequences found in current databases. The SM^3 competence project has the goal of developing nanofabricated fluidic-based systems designed to control and move single molecules and to enable single-molecule measurements. Single-molecule measurement has the potential to provide new information and a level of measurement certainty that does not exist in the methods that have been used in genomics up to this time. By combining the division's existing capabilities in MEMS with the advances in photolithography and etching that have occurred in the semiconductor industry, a new class of device called NEMS (nanoelectromechanical systems) is now possible. The smaller feature sizes of these devices permit the fabrication of fluidic filters that are capable of sorting molecules on the basis of molecular size. Further, by creating nanopore devices through which molecules can be made to move one at a time, individual nucleotide base pairs within a DNA molecule can be determined, providing a quick and accurate determination of the DNA sequence. SM^3 project deliverables include the production of NEMS devices and systems, including that of well-characterized nanoscale fluidic devices and nanopores. They also include single-molecule structural determination and DNA, RNA, and protein-binding measurements.

Current methods of fabricating electronic devices are fast approaching the physical limits of their capabilities. In order to continue the miniaturization of these devices, industry is looking toward molecular electronic and nanosilicon structures that might perform the functions of conventional silicon or compound semiconductor components. The goal of the Nanoelectronic Device Metrology project is to develop testbed structures to make reliable measurements of small assembled molecules and silicon-based nanoelectronic devices. This collaboration with other NIST laboratories and with a number of companies, universities, and government laboratories is utilizing state-of-the-art technologies. These collaborations will enhance the effectiveness and relevance of the proposed work and will supplement the laboratory resources for fabrication and production of test structures. The first efforts to make C-V measurements on molecular electronic devices provided by Hewlett-Packard, mentioned earlier, have been successful.

The panel was given a brief update of recent accomplishments in the Office of Microelectronics Programs. The OMP matrix-manages the National Semiconductor Metrology Program (NSMP), a NIST-wide effort designed to meet the highest-priority measurement needs of the semiconductor manufacturing industry and its supporting infrastructure as expressed by the ITRS and other authoritative industry sources. The OMP currently has a broad portfolio of projects conducted in six of the NIST Measurement and Standards Laboratories. In response to last year's recommendation, the OMP has facilitated the formation of "birds of a feather" groups consisting of experts in common areas to address common problems. One group was formed to address particle analysis methods. This group made a major breakthrough as a result of the shared learning that occurred. Also in response to recommendations made last year, the OMP extended the use of its "Industry Scorecard" metric beyond use as a performance metric to facilitate communications between NIST and its customers. Finally, the OMP incorporated an industry road map benchmark requirement as a standard part of program-funding requests and reviews, also in response to panel recommendations.

Program Relevance and Effectiveness

The Semiconductor Electronics Division, through its in-depth knowledge of semiconductor measurement needs and an excellent strategic planning process that continues to improve each year, has engaged in key programs that have immediate and long-term benefit to the semiconductor industry. Two new long-range competence projects, SM^3 and Molecular Electronics, are expected to result in the development of new laboratory capabilities and to enable NIST to be prepared for key future developments. The panel highlights some key examples of program effectiveness below.

The Linewidth Standards for Nanometer Metrology project has resulted in the delivery of a successful three-dimensional standard that meets ITRS scaling needs. The production of this standard has been successfully transferred to a commercial supplier. Similarly, two-dimensional and three-dimensional dopant profiling using scanning capacitance microscopy has resulted in the most advanced capability in this area, although it does not yet meet ITRS requirements.

Silicon dioxide is still the only gate dielectric in high-volume manufacturing, and it will remain so for the near-term and midrange future. The Advanced MOS Device Reliability and Characterization project has successfully kept pace with mainstream ITRS requirements for silicon dioxide measurements. Division standards are now being adopted internationally.

The Metrology for Simulation and Computer Aided Design project continues to provide state-of-the-art capability for the measurement of silicon carbide diode switching characteristics at critical operating conditions. This provides improved insight into device operation for future device improvement. The division has also developed a highly relevant state-of-the-art thermal imaging tool and is preparing to transfer this tool to industry.

The panel has seen a significant broadening in the objective of the MEMS project, which has been extended to include biological measurements. This change resulted in the funding of a new competence project, SM^3, in collaboration with the NIST Biotechnology, Analytical Chemistry, Optical Technology, Quantum Physics, and Magnetic Technology Divisions. Measurement objectives have been clearly and artfully described by computer-generated models. As a collaborative thrust, this research program will gain the benefit of the multidisciplinary perspective available within this team. With the widespread interest in the human genome, the project is timely and may have applicability in the "war on terror." Progress in this project could enhance U.S. competitiveness in molecular biology and biotechnology by enabling faster, more accurate measurements of DNA and protein sequencing. Areas of application might include the pharmaceutical, biotechnology, and ultra-high density data storage industries.

The division also continues to develop MEMS-based IC test structures that can be incorporated into common IC process technology. NIST has demonstrated the ability to use this technology to measure the elastic properties of thin films utilized in silicon IC manufacturing and bond pad temperatures during the wire-bonding process. While a significant amount of development remains to be done before these tools can be routinely applied by the semiconductor industry, the division has demonstrated how MEMS-based tools offer unique solutions to common silicon IC manufacturing problems. In addition, the division has played a significant role in teaching the industry how to use this technology to measure stress and strain through an interactive Web site (www.eeel.nist.gov/812/test-structures/index.htm).

The Semiconductor Electronics Division and the Office of Microelectronic Programs have played a key role in International SEMATECH and Semiconductor Industry Association (SIA) Metrology Working Groups that set the metrology requirements in the ITRS. Division staff assume leading roles in U.S. standards committees that generate new and better methods for critical industrywide measurements for the semiconductor industry. Examples include the oxide quality-measurement methods approved by the JEDEC-Solid State Technology Association[4] to verify the uniformity of offshore IC foundry products. The South Korean NMI is adopting a number of NIST-developed methods to meet that nation's industry needs. The division's role in organizing the International Conferences on Characterization and Metrology for ULSI [ultralarge-scale integration] Technology is a particularly valuable leadership activity. The next conference is scheduled for 2003 and is expected to result in another 700-plus-page hardbound proceedings volume published by the American Institute of Physics. The volume resulting from the conference is 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.

In order to further the development of high-power devices, the semiconductor industry requires better test and measurement tools, device-modeling capability, and improvements in package design. The Metrology for Simulation and Computer Aided Design project has uniquely addressed industry needs by developing tools and methodologies that are the best in the world and has offered these tools as an unbiased and independent resource. In doing so, NIST has maintained a noncompetitive relationship with industry, universities, and the DOD community.

The division participated in the American Society for Testing and Materials (ASTM) "round robin" correlation tests on MEMS devices designed to measure stress and strain. The results concluded that there are discrepancies caused by differing measurements of the length of cantilever beams in the MEMS devices. Work is under way to understand the measurement errors and generate standard test methodologies.

[4]JEDEC was once known as the Joint Electron Device Engineering Council.

TABLE 2.3 Sources of Funding for the Semiconductor Electronics Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	7.7	7.2	7.5	7.5
Competence	0.1	0.2	0.4	0.5
ATP	0.6	0.4	0.4	0.1
Measurement Services (SRM production)	0.0	0.0	0.0	0.1
OA/NFG/CRADA	0.2	0.3	0.1	0.3
Other Reimbursable	0.1	0.0	0.0	0.0
Total	8.7	8.1	8.4	8.5
Full-time permanent staff (total)[a]	45	39	38	37

NOTE: Sources of funding are as described in the note accompanying Table 2.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

Division Resources

Funding sources for the Semiconductor Electronics Division are shown in Table 2.3. As of January 2002, staffing for the Semiconductor Electronics Division included 37 full-time permanent positions, of which 31 were technical professionals. There were also 29 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The division continues to improve its relevance to industry in spite of flat operating budgets. Through collaborative efforts it has been able to have new programs funded and to improve its clean-room capability with the addition of a major new tool. The division has redirected internal resources and also participated in collaborations with other NIST laboratories so that a major thrust in GaN characterization could be assembled, and at the same time it successfully maintained program efforts in oxide reliability, new dielectric characterization, linewidth metrology, MEMS, and other areas.

Despite these successes, the division will be challenged to keep pace with fast-moving industry need for measurements, standards, and new metrology methods. Many areas in the ITRS have no known measurement solutions. Industry has standards needs today that NIST does not have resources to provide. For example, more rapid progress is needed in the development and transfer of CD linewidth, dopant profile, and thin-film thickness standards. Although the new NIST standard for CD measurements from 90 to 120 nm is a major breakthrough, it does not fully meet the most demanding needs of current CMOS production technology with gate lengths as small as 53 nm. Two- and three-dimensional dopant depth profile standards are currently unavailable to industry. As a final example, NIST certified film thickness standards representative of today's technology—such as silicon dioxide films of the 1.5 to 5 nm thickness—are not available. New capability and infrastructure will be necessary for the division to remain relevant. More experts in new areas and better use of existing staff will be required.

The division's microfabrication facility currently is the only clean room at NIST with semiconductor device processing capability. This facility was very successfully restored to full operation 2 years ago, and it is now being used by seven divisions within NIST. However, the majority of the equipment in this facility is old and obsolete by industry standards.

The Advanced Measurement Laboratory currently under construction is essential to support the exacting future metrology needs that have been identified by the semiconductor and other nanotechnology industries. The capabilities of this new facility will provide a key opportunity for NIST to add new state-of-the-art semiconductor device processing capability and state-of-the-art measurement tools and other infrastructure required to support NIST's mission in support of industry. At this time, no overall plan exists for the use or equipping of the AML facility. An overall strategy needs to be developed on how this facility can best be used to support the NIST mission. This strategy should include a prioritized list of key capabilities to be enabled by the facility. A committed budget for operational staffing and equipment needs to be developed once the key capabilities to be housed there are determined. A budget is needed for state-of-the-art equipment that can make full use of the building's unique environment. This is an opportunity for NIST, in cooperation with industry, to identify key needs that can be addressed at this facility.

The Thin Film Process Metrology project has suffered a reduction in full-time-equivalent research staff at a time when the needs for thin-film process metrology are growing. The panel recommends more effective collaboration between this and other projects within the division to best utilize the limited resources. A positive first step toward that would be to jointly measure the same set of high-k samples with the Advanced MOS Device Reliability and Characterization project to establish possible correlations between optical and electrical properties.

In the Thin Film Process Metrology project, the resources are leveraged through extensive collaborations with industry and academia, where most of the test samples are fabricated. This gives the division little control over the quality of the test samples it measures, especially the high-k dielectrics. Since it is not expected that significant incremental resources will be available to establish comprehensive in-house sample fabrication capability in the foreseeable future, it is very important for division researchers to make judicious choices of the test samples.

The division transferred one of its two molecular beam epitaxy (MBE) machines to Wright Patterson Air Force Base in exchange for a commitment by the base to meet NIST's future compound semiconductor fabrication needs. The second MBE machine was transferred to NIST Boulder where it could be redeployed to other NIST program needs. This improved the division's resource base for addressing key measurement needs.

Radio-Frequency Technology Division

Technical Merit

The mission of the Radio-Frequency Technology Division is to provide the national metrology base for characterization of the electromagnetic properties of components, materials, systems, and environments throughout the radio spectrum. The division is divided into two groups: the Radio-Frequency Electronics Group and the Radio-Frequency Fields Group.

The division continues to progress in aligning its projects to the needs of the telecommunications and wireless markets and has made impressive progress in forwarding new programs. The discussion below highlights projects within the division that are advancing the state of the art.

Researchers in the Noise Standards and Measurements project have completed the development of noise parameters for multiport amplifiers, particularly differential amplifiers—which is critical because of the increased use of differential amplifiers in cell phones and other applications.

The Non-linear Device Characterization project has resulted in generalized, measurement-based models of nonlinear circuits and time-and-frequency-domain models for verification devices. Division researchers have also implemented and demonstrated modulated signal measurements that are critical for the wireless communications industry. This effort includes collaboration with world leaders in instrumentation and nonlinear theory and techniques. The division has demonstrated artificial-neural-network applicability to the estimation of nonlinear scattering parameters and has developed improved simulation for nose-to-nose calibration, which are leading-edge developments.

In a collaboration with the Optoelectronics Division, researchers in the High-Speed Microelectronics project have completed an initial comparison between the sampling scope nose-to-nose and electro-optic sampling system calibrations. Good results were obtained from this comparison. Division researchers also developed a frequency-domain method of characterizing high-impedance probes suitable for performing noninvasive on-wafer waveform and signal-integrity measurements. Through an interdivisional collaboration, researchers are developing a mismatch correction algorithm for time-domain electro-optic sampling systems, an important advance in metrology for the photonics community, specifically addressing component characterization at 40 Gb/s and higher data rates.

The division has also developed high-speed microelectronics metrology techniques that support on-wafer metrology, including the fabrication of coplanar and microstrip calibration standards; the development of measurement methods for scattering, impedance, and noise parameters; and the development of methods for the characterization of complex interconnect structures. Division researchers have continued the development of a causal microwave circuit theory whose voltages and currents reproduce the temporal behavior of the actual electric and magnetic fields in the circuit.

The Electromagnetic Properties of Materials project is aligned with industry, DOD, and the National Institute of Justice to develop new and innovative materials measurement methods. Division researchers developed a new cavity method for thin-film characterization and a variable-temperature low-loss-dielectric measurement system. Project researchers are also characterizing phantom materials—synthetic materials that emulate the conductivity of human body tissues for use in tests of metal detector performance.

The Standards for Broadband Wireless Access project continues to provide leadership in standards for the wireless industry. A single air interface standard (IEEE 802.16) for licensed and unlicensed frequency bands in the range 2 to 66 GHz has been approved.

Electromagnetic compatibility (EMC) measurements of 1 GHz and higher are being advanced. The division is providing useful information to the EMC community and is working to develop acceptance criteria and site calibration methods for open-area test sites at frequencies greater than 1 GHz. The division is also assisting in the development of standards for the use of nontraditional test facilities such as reverberation chambers and gigahertz transverse electromagnetic mode cells. This work is beneficial to International Special Committee on Radio Interference (CISPR) Subcommittee A and to American National Standards Institute (ANSI) C63 standards committees.

The Antenna Metrology project continues its work in millimeter-wave measurements. The millimeter-wave planar near-field measurements will provide U.S. industry the capability to characterize the antenna systems that are required to support emerging technologies such as automobile anticollision radar. This extension of the division's current capability from 75 GHz up to 110 GHz poses challenges that, if met, will provide the fundamental technical basis that U.S. industry can follow when working with these technologies.

In order to meet the ever-increasing demands of government and industry, NIST recognizes that it must expand its frequency coverage for antenna calibrations and services. To ensure measurement accuracy, an assessment of the quality of the illumination of the measurement system must be determined. The division has developed an innovative technique for characterizing measurement facilities; this technique detects and identifies unwanted RF sources and aids in their ultimate removal.

The division has designed and tested a near-field standard probe incorporating a loop antenna with double gaps. The probe provides the capability to measure both electric and magnetic fields simultaneously. The electro-optic probe is fundamental to providing electromagnetic interference testing capability in areas close to source antennas and near large test objects such as aircraft.

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

Program Relevance and Effectiveness

Through the Power and Voltage Standards project, the Scattering Parameters and Impedance project, and the Noise Standards and Measurements project, which all focus on calibration services, the division provides industry with a variety of core measurement services in RF power, impedance, voltage, and noise. It also provides transfer standards over the frequency range 10 kHz to 110 GHz. These services are important for underpinning industrial measurement, research, and development. The division has increased the level of automation of its services to meet customer needs for speed of execution and low cost. The division has also improved the uncertainty of voltage standards for 2.4-mm coaxial power detectors and developed new capability for calibrating 2.92-mm power detectors in the 0.05- to 40-GHz frequency range. It has also developed noise standards and measurements software for analyzing noise-figure measurements. New noise-parameter measurements are under development.

The division's research programs are providing key measurement capabilities to the wireless industry, the photonics community, and semiconductor manufacturers. The Electromagnetic Properties of Materials project is supporting many materials measurements needs of the microelectronics, health care, and biotechnology industries. Measurements of low-k dielectrics were made using International SEMATECH-supplied wafers and NIST-developed transmission line methods. Technical Note 1520 was completed summarizing low-temperature cofired ceramic substrate high-frequency measurement technology.

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 those of traditional EMC test facilities. NIST is working to provide data to standards-writing bodies to aid in the development of new standards that will utilize these chambers. This is important to myriad industries, such as automotive and aerospace firms and the telecommunications industry, that incorporate electromagnetic components into their products.

The public continues to be concerned about the potential for harm from low-level electromagnetic waves from cellular telephones and other devices. Research on health effects to date has been inconclusive, with many studies showing a lack of understanding of basic RF measurement processes by biological researchers. NIST is providing the National Institutes of Health (NIH) 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 rodent RF exposure studies.

The Radio-Frequency Technology Division is the primary provider of antenna probe calibration services to U.S. industry and other government agencies. The division develops standards, methods, and instrumentation for measuring the critical performance parameters of antennas and their associated systems. It is currently working closely with the spaceborne phased-array community on techniques for remotely calibrating large, high-performance, phased-array antennas, such as those used in spaceborne synthetic aperture radar systems.

In collaboration with the division, DOD and the radar cross-section (RCS) industry have created and implemented a National DOD Quality Assurance Program for RCS measurements. A recently completed DOD demonstration project evaluated three classes of RCS ranges. The division worked with DOD and the RCS community to establish the calibration and documentation standards. It played a vital role in developing an uncertainty analysis procedure for the measurements (NISTR 5019) and in participating in the formal reviews of the selected RCS ranges.

The Radio-Frequency Technology Division 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 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. These efforts include having representatives in standards activities run by the International Electrotechnical Commission, CISPR, ANSI, the Society for Automotive Engineers, the U.S. Council of Electromagnetic Laboratories, and IEEE.

The division has taken a proactive role in the development of technically superior standards for wireless communications. Its current focus is on fixed broadband wireless access systems, which have the potential to provide competitive alternative connections to Internet, voice, and video networks for residential and business sites. Spectrum for these services is in private hands, but the wide-scale deployment of systems awaits standardization. To this end, the division has worked to accelerate the approval of the necessary standards. However, the work performed was administrative, not technical. Core metrology programs in the division are in need of resources that could be made available if this administrative support for standards development were moved to another unit in NIST. The panel is not certain that the Radio-Frequency Technology Division is the appropriate body within NIST to take on this effort and recommends that NIST consider where the effort could be most appropriately housed.

Division Resources

Funding sources for the Radio-Frequency Technology Division are shown in Table 2.4. As of January 2002, staffing for the division included 52 full-time permanent positions, of which 48 were for technical professionals. There were also 10 nonpermanent or supplemental personnel, such as post-doctoral research associates or temporary or part-time workers. The division is making a conscious effort to increase collaborations and leverage resources by hosting several guest researchers and using student employees.

Significantly affected by the loss of several key personnel owing to illness and retirement, the division has responded by realigning its staff and hiring several key individuals to complement its current capabilities. These changes position the division well for the future. Even with the pressure to do more with less, the current staff appear to be highly motivated and to be seeking ways to perform their work more efficiently, especially in the areas of calibration and characterization.

The panel observes that flat budgets year after year have resulted in a shrinking workforce within

TABLE 2.4 Sources of Funding for the Radio-Frequency Technology Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	6.1	5.9	6.1	6.4
Competence	0.4	0.4	0.5	0.2
ATP	0.0	0.0	0.2	0.4
OA/NFG/CRADA	1.7	1.9	2.3	2.7
Other Reimbursable	1.0	1.2	1.2	1.3
Total	9.2	9.4	10.3	11.0
Full-time permanent staff (total)[a]	56	57	53	52

NOTE: Sources of funding are as described in the note accompanying Table 2.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

the division. Succession planning factored in with strategic planning is critical to the division's future and must be done before staff size shrinks to the point that critical work cannot be continued while new capabilities are developed. A strategic plan covering the next 5 years would serve as a useful tool in the human resource planning process as well as in prioritizing programs in a changing environment. Broad guidelines for strategic planning should be developed at the laboratory level, whereas the division level is appropriate for detailed planning and ownership. As with all the divisions, the Radio-Frequency Technology Division should develop long-range plans based on technology trends, and these long-range plans should be incorporated in the EEEL budget process to provide adequate personnel, facilities, and equipment resources.

The panel again notes that the status of Building 24 in Boulder is marginally functional. Road construction next to the facility has been completed, and the air conditioning system has been installed. However, the air conditioning and humidity-control system needs to be adjusted and the fire protection system installed before the facility can be considered truly operational. The current state of the facility will significantly compromise the division's ability to perform near-field antenna pattern measurements as it pushes to higher frequencies.

Each facility used by the division must be able to control its environmental factors. Without this ability, the quality of the final product delivered to the customer is significantly degraded, if not compromised. Attempting to retrofit environmental controls after construction is very inefficient and expensive.

The division has developed a proposal for a new, world-class radio-frequency electromagnetics experimental research and measurement-standards facility. The proposed Radio-Frequency Electromagnetic-Field Metrology Laboratory (REML) would provide the capability for addressing a broad range of national and international requirements for precise characterization of free-space and bounded electromagnetic (EM) fields throughout the radio spectrum. Owing to the pervasive use of wireless communications and other emerging electronic technologies, the performance of measurements and calibrations outdoors is becoming less feasible. Because of the laboratory's proximity to potential transmitter locations, the Boulder EM measurement facilities will likely be adversely affected if high-definition television (HDTV) networks become operational over the next several years. Other countries have invested in developing next-generation electromagnetically shielded indoor measurement, research, and calibration facilities. This new facility is critical to the future success of the Radio-Frequency Technology Division. The proposed new facility would also consolidate the electromagnetic field laboratories and personnel under one roof, fostering increased interaction and collaboration as well as increased efficiency in meeting customer needs. The formal engineering and architectural study for the REML has not been performed, but short-term plans for enhancing the existing laboratories will result in more resistance to developing the REML. The panel urges the division to complete a formal engineering study for the REML and to secure top-level NIST support for the facility. In addition to developing the REML facility, strong consideration should be given to building a new open-area test site facility at the nearby national radio quiet zone.

Electromagnetic Technology Division

Technical Merit

The stated mission of the Electromagnetic Technology Division is to enhance the nation's competitiveness by creating, developing, and promulgating state-of-the-art measurement capabilities and standards using quantum phenomena, the low thermal noise available at cryogenics temperatures, and fabrication of specialized integrated circuits, including nanometer-sized devices; emphasizing electrical standards; using unique technical capabilities to assist other NIST organizations with exceptionally difficult measurements; determining data, theory, models, and materials necessary to effectively apply results; and assisting other industrial, government, and scientific organizations to adapt division-developed techniques to their needs.

The Electromagnetic Technology Division is focused on developing electronic standards and measurement techniques based on quantum effects unique to cryogenic and nanoscale devices. This division has been highly successful at implementing such phenomena to achieve unparalleled precision in a range of standards applications and in developing instruments to solve challenging measurement problems. In the past year, several of these standards and instruments have been successfully transferred to other divisions within EEEL and to other laboratories within NIST; they are having considerable impact on work in those programs. In addition, the division's world-class investigators have made significant contributions to the understanding of fundamental science and have proposed new standards based on these advances. New efforts in quantum cryptography and quantum computing have produced promising results, and existing capabilities are being directed to problems in the NIST Strategic Focus Areas of homeland security and nanotechnology.

The Electromagnetic Technology Division does not focus on a single industry, but sees its overall mission as the development of unique standards for a wide range of electrical- and electronics-based industries. Its focus extends beyond the development and maintenance of electrical standards to issues regarding measurement instruments and techniques, including advanced device-fabrication technologies. The division balances its responsibilities to industry, government, and scientific organizations with programs directed toward fundamental work that can potentially lead to new standards, primarily in quantum phenomena. This exploratory work is an essential element of the division's value.

A major reorganization of the division's program took place during the past year, resulting in a realignment of existing efforts and in the initiation of new program directions. The reorganization was driven in part by several personnel changes, most notably by the untimely death of a long-time staff member who was an expert in high-temperature superconductor thin-film device fabrication and physics. The reorganization was also motivated by the need to balance the size and resources of the division's projects. The division now works on the following four projects: Quantum Voltage, Cryogenic Sensors, Nanoscale Cryoelectronics, and Terahertz Technology. Each of these projects has a leader, with all the management responsibilities that group leaders have in other divisions. The projects tend to be smaller than those in other EEEL divisions.

The Electromagnetic Technology Division has a well-focused research agenda and is doing outstanding work in each of its four projects. The strength of this program largely stems from three factors: (1) an extremely talented staff, which includes staff scientists who are recognized worldwide for their leadership and innovation in electronic devices, qualified technicians, and bright postdoctoral associates; (2) a strong facility infrastructure for device fabrication and testing; and (3) effective management. Division management has done an excellent job of focusing resources on activities that fulfill the division's obligations to the mission of NIST and to its broad customer base. At the same time, management has established a scientific climate promoting creativity in exploratory research that is making a significant impact in fundamental science and positioning the division to develop new standards in the future. Combined, these assets make for a highly successful and dynamic division.

The Quantum Voltage project develops new AC and DC voltage standard devices based on superconducting Josephson integrated circuits, and it develops metrology systems using Josephson arrays. The project continues to upgrade the performance and user-friendliness of the conventional DC voltage standards. A portable 1-V DC standard chip has been successfully packaged and operated on a 4-K cryocooler. Windows-based control software for a 10-V Josephson standard has allowed remote operations, thus reducing the costs of the system by facilitating off-site maintenance and allowing it to be more compatible with present-day computer operating systems. A significant advance toward creating lumped arrays of Josephson junctions for the AC voltage standard has been made by using stacked titanium-barrier junctions. More than 2,000 doubly-stacked junctions have been connected in series, and tests have demonstrated the first constant voltage steps, which are essential for the AC standard. These stacked junctions will be important for the programmable AC and DC voltage standards and for systems with improved bandwidths and operating margins. The division now seeks to fabricate arrays that perform as lumped circuit elements at microwave frequencies. The technical challenge is to pack these arrays into a space of less than one-quarter of a wavelength. The stacked titanium-barrier junctions help meet this challenge, but reproducibility of the current system must be improved. Other materials systems such as Nb-PdAu bilayers, yttrium-barium-copper oxide (YBCO) in-line junctions, and Ga-damaged Nb are also being studied.

Work on the Josephson arbitrary waveform synthesizer for AC and DC voltage standards continues to progress. Researchers have been able to increase the output voltage to 177 mV peak-to-peak and have demonstrated improved filters for broadband operation above 10 GHz. The waveform synthesizer will be used as a calculable calibration noise source for an electronically based Johnson noise thermometer. The division has completed needed cross-correlation electronics, and preliminary tests of these electronics are under way.

The Cryogenic Sensor project, now quite mature, is a tightly focused program based on state-of-the-art infrared and x-ray microcalorimeters that employ superconducting transition-edge bolometers as detectors of radiation. The project seeks to develop these systems and to apply them to measurements of electromagnetic signals for applications in the semiconductor industry and in astronomy. The division now seeks to produce user-friendly systems that combine quantum efficient superconducting detectors operated at low temperatures coupled to efficient room-temperature electronics for data processing. This ambitious engineering strategy is necessary to make the technology accessible to customers. The panel was impressed with progress made on the x-ray microanalysis of particle contaminants in semiconductor processing. This technology is now being commercialized worldwide, and two U.S. companies have been licensed by NIST to implement the technology.

A milestone in the Cryogenic Sensor project has been the placement of an x-ray microcalorimeter in the Chemical Science and Technology Laboratory. This instrument is now in full operation and is achieving unprecedented energy resolution in the microanalysis of thin film and particles. The CSTL is using this instrument to map out the L and M energy lines of elements that have previously been difficult to resolve.

Significant progress has also been made in the Cryogenic Sensor project in the development of microfabricated superconductor bolometer arrays. This research seeks to increase the count rate, reduce data acquisition times, and achieve improved spatial resolution for imaging with these detector arrays; the implementation of an improved scheme for the multiplexed readout of the arrays is also included. This approach should prove scalable up to at least kilopixel arrays. One challenge facing this work is the need for a reproducible process for making the bolometer arrays, including control of the superconducting transition temperature of the bolometers and their arrangement in a thermally isolated matrix. New approaches involve sputtered molybdenum/copper (Mo/Cu) proximity bilayers or Mo implanted with magnetic ions for the sensors, and bulk or surface micromachining for the array structure. All the components for the detector arrays are now in place, and the division expects implementation of this technology to occur in the next year. Infrared versions of these arrays are being developed in collaboration with the National Aeronautics and Space Administration (NASA) for radio astronomy detection. The first implementation of an 8-bit multiplexed linear array has been demonstrated at the Caltech Submillimeter Observatory, and prototype two-dimensional arrays are being fabricated for deployment at the James Clerk Maxwell Telescope.

The Nanoscale Cryoelectronics project is developing new technology for electrical measurements such as capacitance and current, including single-photon sources and microwave-frequency metrology for nonlinear superconducting filters. The project's research is based on nanoscale single-electron devices, thin-film fabrication of emerging materials, and micromechanical devices. The fabrication technology for this project relies on its flexible microfabrication facility.

The single-electron devices are being used to develop a portable capacitance standard based on counting electrons. The error rate for the single-electron pump has been measured and compared with theoretical modeling of fundamental noise processes. The resulting confirmation of the theoretical models will allow the operational margins of these electron pumps to be set. In an effort to make the single-electron capacitance standard portable, the electron pump and the electrometer chip have been cycled in temperature to mimic operation in a portable Adiabatic Demagnetization Refrigerator. The daily cycling of the refrigerator did not cause the rearrangement of the offset charges, an encouraging result that is also important for other single-electron devices.

Quantum dots of InAs are being developed as single-photon detectors. By coupling a single-electron electrometer to the QD, single-electron events can be correlated with the single-photon detection. A superconducting Cooper-pair pump has been designed by the division and will be fabricated and tested soon. A superconducting Cooper-pair pump would enable the long-sought quantum-based current standard. This, with the Josephson voltage standard and the QH resistance standard would complete the quantum metrology triangle of current, voltage, and resistance.

Microwave-frequency metrology is being applied to thin-film materials of high-temperature superconductors and ferroelectric materials. The phase relationship between fundamental parameters and higher harmonics has now been modeled, and reference standards are being developed. A superconducting microwave power limiter has been made and tested at 40 GHz.

The Terahertz Technology project combines applications of terahertz radiation for advanced measurements with an emerging program in quantum information processing and computation. The terahertz detection work has two components: imaging and spectroscopy. In imaging, small-scale arrays of fabricated bolometers are being explored for the detection at room temperature of concealed weapons. These are also being used for astrophysical applications at low temperatures (<300 mK). A major milestone in weapons detection was achieved in FY 2001 with the acquisition of a remote image of a handgun made by a scanned single-pixel bolometer. The project now seeks to upgrade to a 120-element focal plane array to allow full-image acquisition in an estimated 20 seconds at a distance of 8 m. In spectroscopy, the project is addressing issues of relevance to both the semiconductor industry and the astrophysical community. For example, submillimeter tomographic spectroscopy is utilizing rotational absorption spectra in molecular gases to monitor 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.

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

The newest and potentially most exciting effort in the Terahertz Technology project is in quantum computation and quantum information processing. The division has demonstrated single-photon counting using a bolometer array with weak coherent photon sources. Single-photon counting is essential for verifying secure encrypted communication via quantum key distribution. The project also explores the use of single Josephson junctions as qubits for quantum computing. The division has demonstrated the entanglement of the ground state and first excited state 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 to assess its potential for quantum logic operations. This effort is directly relevant to NIST's Strategic Focus Area on information technology.

Program Relevance and Effectiveness

Each of the Electromagnetic Technology Division's four projects has well-defined goals directed to satisfying an identified customer need. The Quantum Voltage Project seeks to develop new voltage standard devices based on Josephson integrated circuits and to develop metrology systems using Josephson arrays for customers in the U.S. electronics instrumentation industry, the standards community both nationally and internationally, and the U.S. military. The Cryogenic Sensor project seeks to create unique devices and systems for metrology and instrumentation based on submicron devices and millikelvin temperatures for customers in the semiconducting processing community, the chemical standards community, and NASA. The Nanoscale Cryogenic project will aid and accelerate the development of new thin-film materials and devices for electronic applications, where a key issue has been microwave losses in high-temperature superconductor electronics. The main customer is the telecommunications industry, which is poised to implement high-temperature superconductor filters into cellular base stations. The international standards community is served by the capacitance and current standards developed in this project. The goal of the Terahertz Technology project is to develop sensors in the millimeter-wave and near-infrared regime with improved accuracy, speed, sensitivity, and functionality. Customers for this work include the radiometry and thermometry standards laboratories, NASA, and DOD contractors. The newly formed effort in quantum information science is relevant to national interests in security, communications, and computing.

The Electromagnetic Technology Division delivered a new DC Josephson voltage standard system to the Electricity Division. These programmable voltage standards may soon become the primary source for NIST's voltage calibration services. Intercomparisons of measurements made with these systems are under way with NMIs in Switzerland, the United Kingdom, France, and Japan. This system will also be important in EEEL's Electronic Kilogram project.

The Josephson Arbitrary waveform synthesizer will enhance the metrological precision of the voltage standard and raise its AC frequency range. This system forms the basis for the proposed all-electrical Johnson noise thermometer. In addition, a similar system is being developed in collaboration with Northrop-Grumman for high-performance radar applications.

The Cryogenic Sensor project has several initiatives with potential impact. Microcalorimeter arrays for x-ray and infrared spectroscopy are very attractive to the semiconductor industry and may become a mainline diagnostic tool for manufacturing.

A single-electron capacitance standard with a portable cryocooler is being developed in collaboration with the Electricity Division, to allow a direct comparison with the calculable capacitor. This portable quantum capacitance standard will support industries that manufacture precision electronics instrumentation. The completion of the quantum metrology triangle, if achieved, will also be important for fundamental science and metrology.

The nonlinear microwave response of high-temperature superconducting thin films has been tested and modeled. A nonlinear phase reference standard has been developed in collaboration with the Radio-Frequency Technology Division to support the superconducting filter industry. Also, high-temperature superconducting microwave power limiters have been developed for the Office of Naval Research to protect superconducting transmission lines.

The development of a 100-GHz system for detecting concealed weapons could make concealed weapons detection much less obtrusive and more widely used, saving lives and reducing confrontations. This is just one of many efforts within the division that could benefit the emerging homeland security SFA.

Division Resources

Funding sources for the Electromagnetic Technology Division are shown in Table 2.5. As of January 2002, staffing for the division included 25 full-time permanent positions, of which 23 were for technical professionals. There were also 5 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Personnel issues have been admirably addressed by the hiring or planned hiring of several new staff members and associated technical staff and postdoctoral researchers. This, coupled with its recent reorganization, should put the division in a solid position to proceed with its objectives in the next year.

The division relies heavily on access to state-of-the-art microfabrication facilities for producing submicron single-electron tunneling devices, Josephson junctions arrays, DC superconducting quantum interference devices, and MEMS devices. To provide this capability, a major renovation and expansion of the clean-room facility at NIST Boulder was undertaken during the past few years. The clean room is now in routine operation. In addition to standard commercial clean-room instrumentation, the division has invested considerable time and effort in constructing several state-of-the-art etching systems for specific projects. New systems for lithography, especially a newly arrived pattern generator and a planned new wafer-stepper, will greatly speed and enhance the reliability of mask making and pattern printing.

The microfabrication facility fabricates structures for projects within this and other divisions. All the devices used in the Josephson voltage standards, the single-electronic devices, the single-photon

TABLE 2.5 Sources of Funding for the Electromagnetic Technology Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	4.6	3.2	3.4	3.1
Competence	0.5	0.3	0.5	0.7
ATP	0.4	0.2	0.4	0.7
OA/NFG/CRADA	2.7	2.1	2.4	3.0
Other Reimbursable	0.1	0.1	0.2	0.0
Total	8.3	5.9[a]	6.9	7.5
Full-time permanent staff (total)[b]	38	34	22[a]	25

NOTE: Sources of funding are as described in the note accompanying Table 2.1.

[a]The decrease in funding between FY 1999 and FY 2000 and the decrease in personnel between January 2000 and January 2001 reflect a reorganization in which several projects from the Electromagnetic Technology Division were moved into the newly formed Magnetic Technology Division.

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

devices, and the microcalorimetry projects are fabricated in this facility. Micromachined ion traps are made for use in atomic clocks and quantum computing applications. Surface micromachined thermal isolation structures are made for cryogenic detectors. It is essential that this facility be maintained in Boulder. This is a flexible microfabrication facility that allows lithography on a large range of materials. The work done at this facility cannot be done in a dedicated silicon microfabrication facility because of the stringent and constraining requirements of the silicon process.

Substantial remodeling of several of the large laboratories in the division is nearly complete. However, the age of the building itself militates against effective climate control. The temperature in some of the precision measurement laboratories can vary greatly during the day in the summer. Since this could become a major problem, it would be advantageous for NIST to plan for construction of a new building in the not-too-distant future.

A serious, recent equipment limitation has resulted from high demand for the division's only dilution refrigerator system caused by increased use by the single-electronics research and the initiation of the quantum information effort. A second refrigerator now on order will relieve this problem.

Optoelectronics Division

Technical Merit

The mission of the Optoelectronics Division is to provide the optoelectronics industry and its suppliers and customers with comprehensive and technically advanced measurement capabilities, standards, and traceability to those standards. The division is organized in three groups: Sources and Detectors, Optical Fiber and Components, and Optoelectronic Manufacturing.

The division currently has eight projects: Continuous Wave Laser Radiometry, Pulsed Laser Radiometry, High-Speed Measurements, Interferometry and Polarimetry, Spectral and Nonlinear Properties, Optical Materials Metrology, Nanostructure Fabrication and Metrology, and Semiconductor Growth and Devices. Each project has specific goals and objectives, with cross-project teamwork occurring where appropriate. The division's program is balanced and delivers important calibration services and standards to industry while initiating new activities in emerging technology areas.

The laser radiometry research activities in the Sources and Detectors Group is of critical importance for many areas of the U.S. optoelectronics industry, for semiconductor optical lithography advances, and for other important commercial-sector and DOD programs. The panel was particularly impressed with the division's laser-optimized cryogenic radiometer, its expanded work on high-accuracy optical fiber power calibration sources, and the development of the SiC-based 157-nm excimer laser calorimeter, all of which are essential for next-generation lithographic systems. The latter work, performed in collaboration with International SEMATECH, builds on the division's impressive past work for the 193-nm excimer laser power calibration system, which is currently being used in the development and application of 193-nm semiconductor lithography systems. Division research on beam homogenizer development is essential to further progress. The panel encourages further work in this area and the demonstration of the fully functional calorimeter for 157-nm operation.

The High-Speed Measurements project is well poised to impact high-speed optoelectronic device development and its use in optical information-based technologies. The project's research team has pushed the measurement capability of the frequency response of sources and detectors to include both amplitude and phase and is planning to evolve its measurement capability to 110 GHz by the end of FY 2002. The area of high-speed measurements is of critical importance to optical information technologies and applications. The measurement methods developed will undoubtedly impact high-speed receiver design, high-speed transmitter drivers, and optical-fiber system characterization and measurement systems.

In the High-Speed Measurements project, electro-optical sampling research is important, has great potential for synergistic advances, and needs to be emphasized. The division's application of heterodyne techniques for ultrahigh-speed system analysis is an innovative and important development. Research should continue on understanding the relationships between time-domain and frequency-domain measurements through the development of mathematically rigorous "de-embedding" techniques—for example, optical impulse-response measurements. The panel believes that the electro-optic sampling research performed in the Optoelectronics Division is particularly important for next-generation systems and needs to be accelerated if possible.

Since high-speed measurements require increasing bandwidths, the encroachment of noise into the measurements is unavoidable. For commercial applications, techniques that can provide ultrawide bandwidths with low accompanying noise become critical. The NIST electro-optical sampling methodology is an excellent technique for high-speed sampling. Increasing the stability of the sampling sources and reducing averaging times—especially for measurement techniques in which the high-speed electrical signals are not initiated by the probing optical source and/or real-time applications—can potentially lead to advances in this optical sampling technique. For example, all-optical sampling oscilloscopes and all-optical bit error rate analyzers will be needed for optical information systems operating at 160 Gb/s.

To maintain and push the capabilities of these measurement techniques for emerging applications, new methodologies will need to be developed. For example, current optical information systems are being deployed at 10 Gb/s, with 40-Gb/s systems being designed and planned for deployment in early 2003. In order for NIST to maintain its leadership role, it must look toward the design of systems operating at 160 Gb/s, which will need measurement capabilities in excess of 500 GHz. This added flexibility would undoubtedly increase the versatility of optical sampling, not only for measurements and characterization, but also for the development of new tools that will be needed within the next 3 to 5 years. The panel believes that NIST can achieve these goals with increased personnel and infrastructure.

The quality and direction of the current work in the Optical Fiber and Components Group is world-class, and its accomplishments are critical to the development of optical networks. The panel particularly notes the excellent role that staff members have played in the development of robust, high-reliability wavelength standards that will permit faster expansion of the optoelectronics industry and promote economically viable installation of wavelength-division multiplexing (WDM) communications systems. The Optoelectronics Division excels in the measurement and standards development for polarization-dependent loss (PDL), relative group delay (RGD), and polarization-mode dispersion (PMD) systems. The division has been an innovator and worldwide leader in these important areas. As the performance of commercial optical communications systems increases from 10 Gb/s to 40 Gb/s, these standards activities will increase in importance dramatically. The panel strongly encourages NIST to expand these efforts in support of critical industry needs.

The Interferometry and Polarimetry project focuses on developing measurements and standards for supporting the commercialization of WDM high-speed optical fiber transmission systems. Network and service providers face the dilemma of high operating and maintenance costs and declining revenues and profits. Ultralong-haul (>1,500 km) and high-bit-rate (40 Gb/s) optical networks hold promise for reducing the cost of service and facilitating the rapid positioning of new services. The division's work on chromatic and polarization-mode dispersion, wavelength calibration measurements, polarization-dependent loss, and wavelength shift have been excellent and are key to the successful introduction and deployment of these networks.

The panel notes that the PMD standard development is excellent but suggests that it needs to be implemented in collaboration with equipment vendors and that a suitable partner in the commercial sector should be found. The panel encourages further development of work in these areas and has several suggestions for future directions. Physical PMD standards are useful, but a detailed fundamental standard description of results is needed to define and fully characterize PMD. The panel encourages NIST to quantify PMD compensation and to develop industry standards and understanding of this process. Developing a joint working group with the Telecommunications Industries Association (TIA) and TIA industrial members and engaging in outreach to available resources in industry and academia can help develop a picture of the current status of the understanding and measurement of PMD. Based upon the study of PMD issues, the division should consider forming an industrywide forum on PMD to develop a more complete picture of the problem and its impact on various applications.

The importance of wavelength standards for optical communications systems cannot be overestimated, and the role of the Optoelectronics Division in providing these important standards is extremely important.

The fundamental measurement techniques and standards developed in the Spectral and Nonlinear Properties project are necessary to support the U.S. fiber-optic communications industry. An extremely important area is wavelength calibration transfer standards. The division has produced an SRM for the most commonly used fiber communications band, the C-band of the erbium-doped fiber amplifier. Further funding is necessary to expand these efforts to create an SRM for the L-band and the S-band. In addition to expanding the wavelength range of wavelength calibration services, there may also be a need to increase the wavelength accuracy. A study will be necessary to determine what the ultimate wavelength accuracy goal should be. Two developments potentially motivating higher accuracy measurements are the move to closer wavelength channel spacings (<25 GHz) and the move to systems with multiple filters and wavelength multiplexers and demultiplexers in the line.

The carbon monoxide-based standards developed in the Spectral and Nonlinear Properties project are extremely useful and should result in high demand. The panel strongly supports continued activities in these areas, particularly in the L-band from λ=1565 nm to 1625 nm.

Nonlinearities in optical fiber affect the performance of optical communications systems, and a thorough understanding of the nonlinearities will aid companies in producing better system designs. Applying NIST-quality standards to studies of optical nonlinearities is important. In many cases, the impact of fiber nonlinearities depends on the specific details of the fiber design, so it is important for the division to closely couple its nonlinear studies to the fundamentals of fiber design. In particular, nonlinear performance should be described in terms of accurate measurements of fiber power, core diameter, index of refraction, and any other pertinent parameter. There is a need for accurate power measurements for fiber power levels much higher than the currently supported 50 mW. The division's work on nonlinearities in microstructure fiber seems especially interesting, because it has the potential to discover pertinent fiber parameters for nonlinear frequency generation and to find new ways to characterize the pertinent parameters of these new types of fibers.

An important part of the research on nonlinear characterization is the supporting modeling work. Evaluating the accuracy of various modeling techniques, especially as they relate to Raman amplification and noise generation, could be very important. The panel suggests that the division look for opportunities to transfer its results to industry and verify its models by working with commercial modeling companies.

The Optoelectronic Manufacturing Group effort has continued to develop significant contacts with customers and stakeholders through direct contact with users, participation in technical conferences, workshops of the Optoelectronics Industry Development Association, and the publication of results. The group has published results in archival journals and given presentations at relevant technical conferences. Developing low-cost, reliable manufacturing techniques, monitoring and measurement techniques, and SRMs remains of great importance for the U.S. optoelectronics industry, especially as many device companies continue to expand their use of outsourcing for semiconductor materials from epitaxial foundries. The work of this group in developing new standards for materials and processes is important and well justified. The panel continues to believe that a focus on in situ approaches to the metrology of epitaxial layers during growth and to the development of standard reference data and materials should be emphasized.

Materials purity is of paramount importance to improving many device performance characteristics. As the panel has previously noted, measurements of the purity of source materials (particularly gaseous source materials) is a critical area that has the potential for broad impact in compound semiconductor research and manufacturing. The panel applauds the division's work with gas vendors to establish commercially viable advanced techniques for the analysis of water in the hydride precursors used in vapor-phase epitaxy and metal-organic chemical vapor deposition growth of III-V materials (e.g., arsine, phosphine, and ammonia). The division's collaboration with the NIST Chemical Sciences and Technology Laboratory is also very important. The panel continues to encourage emphasis on the development of in situ techniques for real-time analysis of purity.

The panel strongly supports the development of alloy composition SRMs and the refining of measurement techniques to determine the alloy composition and thickness of compound semiconductor epitaxial layers. The focus should continue to be on the development of accurate techniques for the determination of alloy compositions and uniformity, especially in the high-Al-composition regime for AlGaAs alloys, and on the effect of AlGaAs alloy composition variations on the oxidation properties of these materials. Measurements of composition uniformity in InGaAsP should also be continued, in close collaboration with industrial partners. The division should focus on performing analyses with accuracies that are not within the capabilities of commercially available equipment. In doing so, emphasis should be placed on improving the performance and accuracy of commercially available techniques (such as photoluminescence and photoreflectance mapping, and x-ray diffraction mapping) and the development of new techniques (such as microfocus x-ray and micro Raman).

The panel is pleased to see the molecular beam epitaxy III-V activity refocused on the growth of InAs quantum dots and the establishment of a future standards development activity on such nanostructures. The work on photon turnstiles and quantum cryptography and studies of single-electron devices using these QD materials are also of great potential interest. It is important that the development of electronic models for single-photon turnstiles and photonic crystals be carried out in a timely fashion in order to provide direction for the work and also to indicate the viability of InAs QDs for this purpose. Collaborations with other NIST organizations have been developed, and further pursuit of such interactions is encouraged. If appropriate materials can be obtained from collaborators or vendors, this route should be pursued. The work on electrical contacts to individual QDs should be carried out in some way that will provide electrical injection into covered QDs (i.e., QDs with an appropriate passivation or cladding layer), since it is likely that surface states will limit the performance of bare QD electronic structures.

Program Relevance and Effectiveness

As discussed above, the overall relevance of the Optoelectronics Division's projects is very high. The division's impact on the U.S. industry has been significant and is of increasing importance. Division programs support many sectors of the optoelectronics industry and the semiconductor industry. The measurements and standards that the division is developing and supporting enable systems that are key to the development of viable, cost-effective, high-speed optical networking and communications. As these systems come closer to deployment, the need for standards and measurements in this area grows. To fully meet these needs would require an expansion of NIST efforts in this area.

The panel believes that the division's important results could be even more widely disseminated. For example, best practices and instructions for key measurement techniques could be placed on the division's Web site, SRMs could be more heavily marketed at meetings of groups such as the International Society for Optical Engineering and the Conference on Lasers and Electrooptics, and division staff could expand their involvement with professional societies and in organizing conferences.

Division Resources

Funding sources for the Optoelectronics Division are shown in Table 2.6. As of January 2002, staffing for the division included 39 full-time permanent positions, of which 34 were for technical professionals. There were also 5 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Funding and staffing limitations restrict the scope of the Optoelectronics Division's projects. The division's funding has not kept pace with the cost of doing leading-edge research and standards development in this rapidly advancing area. Facility deficiencies also hamper the division's work, and upgrades are long overdue. Because the division is working with very limited resources, critical functions are likely underdeveloped. A review of priorities is necessary to assure that the most important programs are funded sufficiently.

The panel is concerned about increases in the relative fraction of non-STRS funds in the operating budget and about the sustainability of the programs based on such "soft" money. The proposed NIST Office of Optoelectronics Programs also needs to be fully funded. The need for this program is increasingly important and relevant to the U.S. economy.

TABLE 2.6 Sources of Funding for the Optoelectronics Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.6	5.5	5.9	5.5
Competence	0.0	0.2	0.2	0.4
ATP	0.6	0.6	0.9	0.8
Measurement Services (SRM production)	0.1	0.2	0.3	0.3
OA/NFG/CRADA	1.1	1.6	2.0	1.9
Other Reimbursable	0.3	0.3	0.5	0.3
Total	7.7	8.5	9.8	9.2
Full-time permanent staff (total)[a]	37	37	35	39

NOTE: Sources of funding are as described in the note accompanying Table 2.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

The panel commends the division on leveraging available human resources through the development of synergistic intradivisional and cross-divisional activities, especially in the areas of electro-optical sampling, supercontinuum and nonlinear properties research, and QD and single-photon turnstiles. Research partnerships have been used very effectively to ameliorate staffing limitations. The panel notes that recent staff hires are relatively early in their careers and consequently, the division's expertise in some areas may have decreased owing to the loss of some senior personnel to the private sector.

Magnetic Technology Division

Technical Merit

The mission of the Magnetic Technology Division is 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. The panel was gratified to see the mission statement modified to include the phrase "strengthen the U.S. economy and improve the quality of life," in response to its comments in last year's assessment. The panel believes that the mission should also reflect the division's commitment to advancing standards.

The Magnetic Technology Division is organized in two groups: Magnetics and Superconductivity. The division has overcome the major challenge posed by lack of leadership with the appointment of a division chief from within EEEL. The new division chief has provided able and effective leadership, and staff morale continues to improve from a low point when the division was first formed several years ago. The division chief is assisted in day-to-day operations by the staff member who is both group leader for the Magnetics Group and acting group leader for the Superconductivity Group. The division needs permanent staffing for both group leader positions but is otherwise effectively organized and is exhibiting steady progress in its organizational maturity.

The Standards for Superconductor Characterization project has made considerable progress in the past year on issues important to the superconductor industry. Significant testing was completed for high-current conductors procured as part of the U.S. contribution to the Large Hadron Collider at the Centre Européenne pour la Recherche Nucléaire (CERN). An important study of residual resistance ratio testing of industrially produced niobium (Nb) plate for high-power accelerator RF cavities was undertaken. Some defects in the test procedure of an industry test subcontractor were identified and corrected. The need for new standards for both high-current magnetic resonance imaging (MRI) conductors and for marginally stable Nb_3Sn conductors has been addressed, and a new working group for critical current testing has been established. A study has been completed on inductive effects in critical current testing, and it explains a common but often ignored feature of critical current tests. Six new International Electrotechnical Commission (IEC) standards have been issued, and another six are being worked on. In short, a significant and strong user interaction has taken place throughout the year, and it both demonstrates and strengthens the relevance of the project to its industry and national laboratory user base.

The Superconductor Electromagnetic Measurements project utilizes unique electromechanical capabilities, is one of very few such projects worldwide, and has an international reputation. In the past year, important critical current versus strain properties measurements were performed on new-generation, very high current density Nb_3Sn wire and on alloy-strengthened Ag-sheathed Bi-2212 wire. The study of cracking mechanisms in Y-Ba-Cu-O-coated conductor prototypes remains a major focus.

Nanoprobe Imaging project researchers have made in situ measurements of ferromagnetic films using MEMS magnetometers. Very small moments can be measured with this technique while the film is deposited, resulting in the potential for accurately controlling the thickness and moment of thin magnetic films as they are being deposited. This technique has the theoretical sensitivity to measure the magnetic equivalent of 0.02-nm-thick Fe film. The technology could potentially be very useful to the data storage industry. The division should now perform a controlled test of this method in a factory to compare it with existing control methods.

Another project result is the development of a microscopic Scanning Microwave Power Meter using dielectric materials. This is very promising for the measurement of microwave field distributions near micrometer-size microwave transmission lines. Good progress has also been made in acquiring the ability to measure spin decay in magnetic nanodots. These technologies show promise in aiding the communications and data processing industries, which need to measure high-frequency signals on a micrometer scale.

In the Magnetic Recording Measurements project, a high-speed version of the nanoscale recording system (NRS) for magnetic tape forensic analysis has been developed. This effort responded to a previous panel recommendation. The new system uses an 8×8 array of magnetic recording elements to increase data rate. NIST has provided the instrumentation and consulting to the Federal Bureau of Investigation (FBI) and the National Transportation Safety Board on data recovery from low-density storage media such as analog, audio, and VHS. NRS has also been used for noninvasive probing of fields caused by currents. NRS has been used in failure analysis and on-chip metrology in the semiconductor industry and has application to relay aging and fault detection. The division also improved the technology this year through the development of software to convert the field map data to a current map.

Excellent progress has been made in developing an integral superconducting flux-measurement loop for absolute calibration and in developing an inductive magnetic standard with a size of approximately 1 square cm and a magnetic moment of 0.1 to 1 memu. A round-robin evaluation to test these technologies is scheduled for 2002. In situ surface magnetometry is of great interest for characterizing the surfaces of thin magnetic layers, which are very common in data storage. These capabilities are badly needed by the data storage industry. Progress continued on the theory of surface states, also important work.

Researchers in the Magnetodynamics project have completed and published several studies on the understanding of high-speed switching in magnetic materials. The work on surface versus bulk dynamics in NiFe, the study of dynamic anisotropy in permalloy films of various thicknesses, and the modeling of damping physics should be of interest both to researchers and to engineers seeking to design high-speed magnetic devices. The study of dynamic anisotropy has raised some interesting questions on the origin of damping, since it cannot be explained by simple dipole-dipole interaction as was previously believed. Work to understand this phenomenon should continue. This work done thus far has been on large permalloy films. The panel suggests that it would be very useful to extend the work to smaller-patterned films representing more closely what would be used in actual devices such as a thin-film writer. The panel also suggests extending the work to high-coercivity films for media. The research team is active in transferring its work to industry and academia. For example, its Pulsed Inductive Microwave Magnetometer (PIMM) is used by several universities and an industrial firm, and the team is collaborating with industry on high-speed inductive current probes. The researchers have also initiated DARPA-funded research on spins in semiconductors and have ongoing collaborations on spin momentum transfer. This work promises to illuminate some of the basic physics associated with using spins in practical devices. New research on spin waves and damping in nanostructures is also of potentially great use to industry in designing nanostructures such as patterned media.

In the Magnetic Thin Films and Devices project, research on switching on spin valves and magnetoresistive random access memory (MRAM) devices is valuable. In MRAM, the switching dynamics and the presence of metastable states are fundamental problems that need to be addressed to determine the commercial viability of MRAM devices. The research on high-frequency magnetic noise in spin valves is valuable because it helps elucidate a potentially important contribution to overall noise of high-density recording systems. This work should be extended using state-of-the-art or near-state-of-the-art heads. The division's research on the control and engineering of magnetic damping should be useful to engineers working on high-frequency devices; that work received much attention from industry in the past year. Research on the measurement of spin wave oscillations, the electrical detection of electronic spin resonance, the in situ measurement of conductance and magnetoconductance, and the on-wafer measurement of magnetostriction are all promising technologies for use in the storage and electronics industry.

Program Relevance and Effectiveness

The Magnetic Technology Division's superconductor work is well aimed at meeting needs of the U.S. superconductor industry and its big project customers in the U.S. Department of Energy (DOE) laboratories. This is illustrated by the strong external funding for its mechanical property research and the wide approval given to the standards work that it leads.

One of the division's main goals is the dissemination of standards to industry. This year saw major progress with the development of a superconducting flux standard, which is ready for dissemination to industry in 2002. Standards are also needed for magnetostriction, magnetic imaging, and related areas. Standards based on quantum mechanics would be a suitable long-range focus for the group, as it would enable a substantial increase in accuracy of the fundamental magnetic standards.

The division has done excellent work in advanced measurement that is highly relevant to industry, government, and the general scientific and engineering communities. This includes work on MEMS magnetometers, PIMM collaboration and measurements, control of damping in engineered materials, dynamic anisotropy, inductive current probe, understanding of inductive effects in high-current superconductor testing, and understanding of coated conductor strain effects. Many of these measurements can be done in situ, which enables process monitoring and control. This will be very valuable in factories of the future.

Much division work involves close collaboration with other government partners. Areas of interest to other government agencies include the high-speed nanoscale recording system for forensic analysis of tapes, spintronics as a promising new technology, arrays of magnetic recording sensors for detection of vehicles, and molecular manipulation as part of the SM^3 competence project.

The division has been effective in disseminating the results of its research. It has trained many first-rate postdoctoral research associates who have subsequently been hired by industry and have thus brought new expertise and knowledge to bear in a broader context. The division has also collaborated with universities, government laboratories (including Lawrence Berkeley National Laboratory, Fermilab, and Los Alamos, Argonne, and Oak Ridge National Laboratories), government agencies (e.g., the FBI, DOE, DOD, and DARPA), and industry partners (including Storage Tek, NVE, Motorola, Veeco, Hutchinson, Energen, Hewlett-Packard, Intel, TPL, 3M, American Superconductor, IGC SuperPower, Oxford Superconductor, Supercon, ABB, Pirelli, Rockwell, Detroit Edison, and Southwire).

The division has been an active participant in the National Storage Industry Consortium (NSIC) Extremely High Density Recording project, which has brought together the key players in magnetic storage from both industry and academia to advance the precompetitive art in recording. The division hosted the NSIC tape road map workshop in 2001 and worked with the International Disk Drive Equipment and Materials Association (IDEMA) on standards. Division staff members regularly chair conference sessions at Intermag, the Magnetism and Magnetic Materials Conference, and the Applied Superconductivity Conference, and serve on conference committees.

Division staff members have published numerous technical articles in quality refereed journals this year, with sizable impact on the technical community. The papers given at the Magnetic Recording Conference and the Magnetism and Magnetic Materials Conference were of particular note. As the IEEE Magnetics Society Distinguished Lecturer for 2001, one division researcher gave 25 lectures around the world on magnetodynamics.

The division participates in numerous standards-setting activities. In 2001, division staff members sat on committees for ASTM, IEEE, the National Electronics Manufacturing Initiative (NEMI), and the International Electrotechnical Commission (IEC).

The division has solicited feedback on its programs through its interactions with IDEMA during the round-robin standards project, the NSIC EHDR program on high-speed switching dynamics, and work with IEC TC90 and the Versailles Project on Advanced Materials and standards committee in superconductivity.

Division Resources

Funding sources for the Magnetic Technology Division are shown in Table 2.7. As of January 2002, staffing for the division included 13 full-time permanent positions, of which 11 were for technical professionals. There were also 7 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Increasing division staffing by one full-time position a year for 3 years would allow the division to undertake new work in spin imaging, spin imaging standards, and standards based on quantum mechanics. The panel believes that such work will be important to future industrial developments.

TABLE 2.7 Sources of Funding for the Magnetic Technology Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999[a] (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	NA	1.6	2.9	2.9
Competence	NA	0.5	0.0	0.1
ATP	NA	0.1	0.1	0.1
OA/NFG/CRADA	NA	0.7	0.9	1.3
Other Reimbursable	NA	0.1	0.1	0.0
Total	NA	2.9	4.0	4.4
Full-time permanent staff (total)[b]	NA	NA	11	13

NOTES: Sources of funding are as described in the note accompanying Table 2.1. NA = not applicable.
[a]Data are not available for years prior to FY 2000, as the Magnetic Technology Division was formed in September 2000 in a reorganization in which several projects were moved from the Electromagnetic Technology Division to this new division.
[b]The number of full-time permanent staff is as of January of that fiscal year.

The panel recommends that further effort be made to consolidate the division's laboratory space, which is now spread out over five buildings. Some of the space is borrowed from other groups and may have to be vacated. Colocating would greatly enhance collaboration and interaction. The renovation of one laboratory that has gotten under way is applauded by the panel. All of the division's laboratories require upgrading.

Some new equipment is being purchased this year, and the division is making an effort to accelerate the repayment of the capital equipment fund for the existing equipment. Nevertheless, there is room for significant upgrading of the division's equipment. In particular, a new deposition system for thin films and an upgrade of the electron-beam facility are encouraged. The present E-beam instrument is an older, modified SEM that has neither the resolution nor the overlay capability of a modern E-beam writer. Improving this capability would allow the division to make more complex structures with smaller dimensions. New equipment would also be easier to use and have higher throughput and better yields than the current equipment. The thin-films project is using home-built equipment, which consumes time that would be better spent doing research. In addition, commercial equipment would produce films more comparable with industry standards at higher throughput. The right equipment would enable the division to put films on wafers that industry uses, and thus results of NIST research could be immediately tested on industry lines and with industry test structures and devices.

The division's two project leaders in superconductors are in the later stage of their careers. A succession plan is needed to avoid loss of expertise and to permit a smooth transition when they leave NIST.

Office of Law Enforcement Standards

The mission of the Office of Law Enforcement Standards (OLES) is to "serve as the principal agent for standards development for the criminal justice and public safety communities." OLES helps law enforcement, corrections, and criminal justice agencies ensure that the equipment they purchase and the technologies they use are safe, dependable, and effective. While it is part of EEEL, OLES is a matrix management organization that works with all of NIST.

OLES's primary customers are the criminal justice and public safety communities. In the criminal justice area, OLES supports law enforcement, courts, corrections, and forensic science activities. OLES focuses on the development of performance standards and conducts research on protective clothing, communications systems, emergency equipment, investigative aids, protective and enforcement equipment, security systems, weapons and ammunition, and the analytical techniques used by the forensic science community. In the area of public safety, OLES supports fire services, hazardous material units, emergency medical services, and the first-responder community. Of key importance is detecting threatening individuals and their weapons. To help do so, OLES has the goal of developing a database of faces to support the development and testing of automated facial recognition systems. The office is also working to develop a monolithic microbolometer array for remote detection of concealed weapons on human beings. In addition, work is under way to develop performance standards for chemical and biological protection, detection, and decontamination equipment for first responders.

The panel was impressed with the scope of OLES's work and its pertinence to the new national focus on homeland security. The current work is divided into six programmatic areas: Weapons and Protective Systems; Detection, Inspection, and Enforcement Technologies; Chemical Systems and Materials; Forensic Sciences; Public Safety Communication Standards; and Critical Incident Technologies. These areas and the projects they encompass are appropriate for OLES and consistent with its mission and that of NIST.

Critical Incident Technologies was established as a separate program area in 2001 in response to the attacks of September 11. The program inherited ongoing work that was relevant to terrorist attacks, such as developing standards for chemical and biological protection equipment for first responders. A first suite of standards, for respiratory gear, was issued in January 2002; this standard was based on 2 years of careful groundwork by OLES. The Critical Incident Technologies program also includes new initiatives, including improving airline cockpit physical security and developing testing standards for frangible ammunition (ammunition that might be used by security agents defending a plane against hijackers—it shatters when it hits a hard structural surface rather than penetrating the surface, thus posing less danger to the plane and passengers). The results of these efforts could be extremely valuable to the nation for deterring or responding to further terrorist attacks. In fact, opportunities to contribute to the nation's homeland security activities exist in all OLES programs.

The breadth of OLES activities means that it is relevant, in fact critical, to the strategic goals of many organizations. As mentioned in last year's report, OLES has already been incorporated into the strategic plan of the National Institute of Justice (NIJ). This year, OLES is featured in the strategic plan of the Interagency Board for Equipment Standardization and Interoperability Working Group, where OLES's role is to administer and promulgate equipment standards suites and to publish, administer, and maintain a set of first-responder equipment guides, which would include test data. OLES also figures in the strategic plan of EEEL and will certainly be a key element of the NIST-level Strategic Focus Area on homeland security. The panel was pleased to see continued strengthening of relationships between the OLES staff and the rest of the NIST staff on the Gaithersburg campus as well as the development of interactions with the U.S. Department of Commerce.

OLES devotes significant effort to determining its customers' needs and disseminating its results to interested parties. Staff serve on technical advisory committees; run training sessions; and attend conferences, meetings, and trade shows to determine research needs and increase awareness of OLES activities. Sponsors of ongoing projects, such as the NIJ, receive quarterly and final reports on their

TABLE 2.8 Sources of Funding for the Office of Law Enforcement Standards (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
National Institute of Justice	5.4	8.4	12.5	17.0
Other agencies	0.2	0.4	0.6	0.3
STRS	0.0	0.0	0.0	0.1[a]
Total	5.6	8.8	13.1	17.4
Full-time permanent staff (total)[b]	9	9	9	10

NOTE: Sources of funding are as described in the note accompanying Table 2.1.
[a]The internal NIST funding (STRS) for FY 2002 is a contribution from EEEL in support of the construction of OLES's new ballistics range on the NIST campus.
[b]The number of full-time permanent staff is as of January of that fiscal year.

projects. However, technical reports, performance standards, test procedures, software, and other OLES products are also made available to other relevant audiences and to the public, frequently by means of the OLES Web site. OLES results are widely used at the federal, state, and local levels, and in other countries as well, and they form the basis for testing and certification programs throughout the criminal justice community. OLES reports that thousands of law enforcement and public safety workers are alive because of the improvements in equipment and procedures that this office has facilitated over the past 30 years.

Funding sources for OLES are shown in Table 2.8. OLES is supported almost entirely by outside-agency funding, primarily from NIJ, the research arm of the U.S. Department of Justice. Other support comes from the National Highway Traffic Safety Administration, the Federal Aviation Administration, the interagency Technical Support Working Group, and the Memorial Institute for the Prevention of Terrorism. The upward trend in funding observed in past years continues and is testimony to OLES's value to its customers. This trend will probably accelerate as OLES expands to fill an important role in the war on terrorism. The panel has noted in past years that the total dependence on external money adds significantly to the administrative burden on OLES staff. OLES must work hard to ensure continuity of funding, which can be especially difficult when other agencies receive their budgets late or if NIST is delayed in processing the paperwork. This is a NIST-wide issue.

As of January 2002, OLES had a paid staff of 10, including 8 technical professionals. Several positions were vacant, including the key role of program leader for Critical Incident Technologies. Office management is creatively seeking alternative ways (such as temporary personnel, staff on assignment from other government units, and so on) to assure that OLES has access to needed expertise. OLES is also looking for a Test Coordinator and Ballistics Range Manager. It is important that this position be filled as soon as possible. A new ballistics range is being constructed on the NIST campus, and OLES is scheduled to occupy it in the fall of 2002. The panel commends EEEL and the NIST Physical Plant unit for supporting this new facility with funding and was pleased to hear of the efforts being made to complete this work in time for a smooth transition of OLES's ballistics program from its current temporary facility.

3

Manufacturing Engineering Laboratory

PANEL MEMBERS

Marvin F. DeVries, University of Wisconsin-Madison, *Chair*
Richard A. Curless, Cincinnati Machine, a UNOVA Company, *Vice Chair*
Hadi A. Akeel, FANUC Robotics NA, Inc. (retired)
Christopher P. Ausschnitt, IBM Microelectronics Division
Robert Bridges, SMX Corporation
Richard J. Furness, Ford Motor Company
Marion B. Grant, Jr., Cummins Technical Center
David E. Hardt, Massachusetts Institute of Technology
Mark C. Malburg, Digital Metrology Solutions, Inc.
Newman M. Marsilius III, PMT Group
Eugene S. Meieran, Intel Corporation
Carmen Pancerella, Sandia National Laboratories
Jay Ramanathan, Concentus Technology Corporation
Wolfgang H. Sachse, Cornell University
Arthur C. Sanderson, Rensselaer Polytechnic Institute
Masayoshi Tomizuka, University of California, Berkeley
Peter M. Will, Information Sciences Institute/University of Southern California
David H. Youden, Eastman Kodak Company

Submitted for the panel by its Chair, Marvin F. DeVries, and its Vice Chair, Richard A. Curless, this assessment of the fiscal year 2002 activities of the Manufacturing Engineering Laboratory is based on site visits by individual panel members, a formal meeting of the panel on March 19-20, 2002, in Gaithersburg, Md., 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 2002*, National Institute of Standards and Technology, Gaithersburg, Md., 2002. Available online at <http://www.mel.nist.gov/proj/bb02.pdf>.

LABORATORY-LEVEL REVIEW

Technical Merit

According to laboratory documentation, 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. This mission statement has one small but important change from previous years: it no longer specifies that MEL meets the needs of "discrete-part manufacturers," but now specifies simply "manufacturers." The panel applauds this change, because it indicates recognition of the changing nature of manufacturing throughout the world, and particularly in the United States, where outsourcing, including outsourcing to overseas locations, has become a major element of the emerging "lean manufacturing" philosophy. In keeping with these new realities of manufacturing, the panel suggests that MEL review and consider the needs of all manufacturers in the supply chain, from large, original-equipment manufacturers down through procuring subcontractors as well as small, discrete-parts manufacturers.

The new mission statement lacks specific mention of information technology or knowledge software, which have become important technology within manufacturing today, and this may merit reconsideration by the laboratory. MEL could also consider changing the verb "to satisfy" in its mission statement to something stronger, denoting the leadership position that it is striving to achieve. Finally, MEL managers at all levels should ensure that the missions of each division dovetail with the MEL and NIST mission statements to form a coherent picture of MEL's role in manufacturing technology.

The quality of research in the laboratory is high overall. In some areas, MEL work is state of the art relative to work being performed worldwide; in others it is not. While recognizing that for some activities it may not be necessary to be world-class, the panel notes that where MEL is not achieving world-class status, it is generally because resources are spread too thinly. Considering current budget and operating constraints and taking into account that achieving world-class status is not possible for every activity, MEL emphasis on collaboration is to be complimented and encouraged. In general, the staff is highly competent and motivated to have a positive impact on U.S. competitiveness and is capable of the technical leadership that MEL should be striving for.

The Manufacturing Engineering Laboratory is organized in five divisions: Precision Engineering, Manufacturing Metrology, Intelligent Systems, Manufacturing Systems Integration, and Fabrication Technology (see Figure 3.1). The first four divisions are reviewed in turn under "Divisional Reviews" below in this chapter; the Fabrication Technology Division, which houses the NIST machine shop, is not reviewed separately, but its "Shop Floor as National Measurement Institute" program is discussed in the reviews of its collaborating divisions.

Program Relevance and Effectiveness

MEL has a unique role to play in U.S. manufacturing through its expertise in measurements and standards of all sorts. The panel was impressed with the number of MEL researchers who had received awards and recognition from external organizations, including international industrial and standards organizations such as IEEE, ASTM, and the International Organization for Standardization (ISO). These awards are evidence of the value that their colleagues throughout the world place on their achievements and contributions to the manufacturing community.

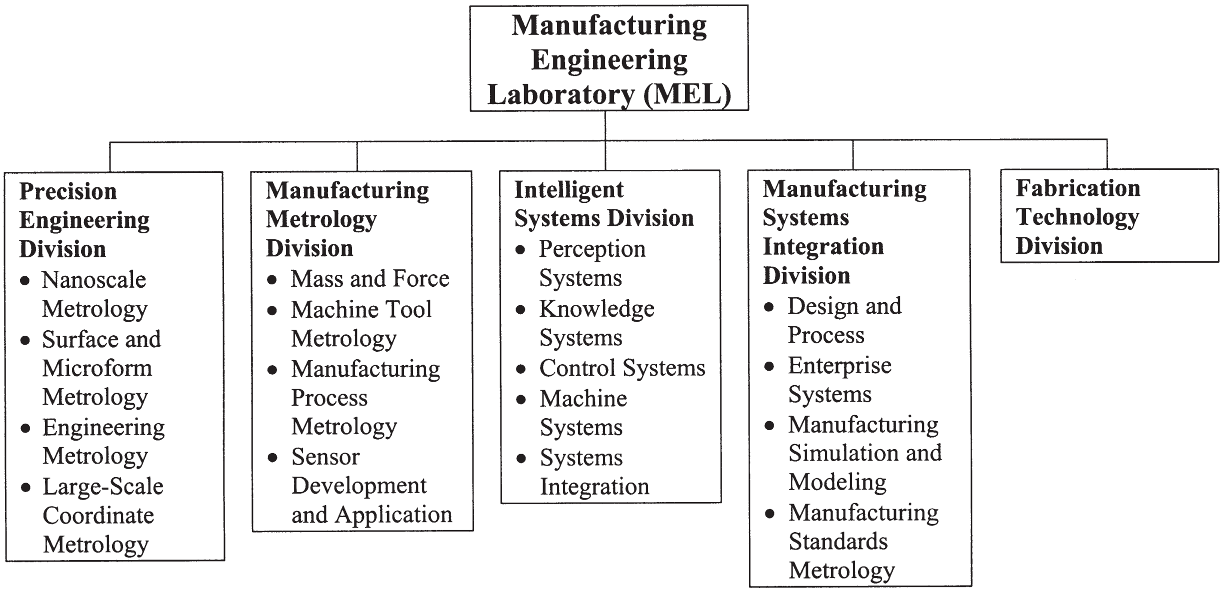

FIGURE 3.1 Organizational structure of the Manufacturing Engineering Laboratory. Listed under each division are the division's groups.

The panel was also pleased to learn of the prestigious Department of Commerce Gold Medal award given to the team of NIST researchers, including MEL staff, for their contributions to the highly visible Charters of Freedom project involving the design and construction of new display and preservation cases for the Declaration of Independence, the Bill of Rights, and the Constitution. This award, along with a Bronze Medal for work on the M48 Coordinate Measuring Machine, provides further evidence of the quality of the research done in MEL.

By refining its own focus and improving its customer focus, the laboratory could achieve even more significant impact from its expertise. The panel has seen increased efforts among MEL staff to identify customers and their needs as a means of directing programmatic efforts. This is responsive to earlier panel feedback on the need to better identify customers.[2]

It is critical that MEL identify its customers correctly, and to accomplish this, the laboratory needs to further refine its idea of the customer. In seeking its customers and their needs, MEL has not yet captured the viewpoint of firms deep in the supply chain. MEL must extend its customer focus in that direction in order to have the level of impact that it seeks. Also, it needs to focus on the needs of users in addition to those of vendors of advanced manufacturing technology. Customer contact should be sought at all levels of an organization, from bench-level scientists through top management. Better definition of the customer will only be accomplished through a combination of top-down and bottom-up approaches, in which strategic management is utilized to determine target industries, and working-level knowledge of those industries is used to target appropriate organizations, firms, and individuals.

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

MEL has made considerable progress over the past several years in program planning and in alignment of the MEL plan with NIST objectives. MEL commitment to long-term program base funding is recognized and applauded. Strategic planning is still being carried out to differing degrees throughout MEL. Planning is not uniform among the divisions, and what planning exists has not yet been fully integrated into programmatic decisions. Many ongoing programs appear to have been started for opportunistic reasons, but that cannot be the major factor driving program prioritization if MEL is to achieve its full potential for impact. As the NIST strategic plan is finalized, the panel anticipates that MEL will revisit its own plan for purposes of its relevance and appropriateness and adjust the MEL plan as necessary. The panel looks forward to reviewing the results of MEL planning processes at its next assessment.

MEL could benefit from a more systematic self-evaluation of its own effectiveness, which would provide it with information needed to optimize the use of resources, especially staff talents. The panel suggests that MEL consider adopting regular use of the Baldrige quality criteria to measure the effectiveness of its staff and the effectiveness and timeliness of its programs and outcomes.

MEL presented the panel with its responses to the newly defined, NIST-wide Strategic Focus Areas. The panel has the following reaction to these presentations.

Homeland Security

In the area of homeland security, critical infrastructure protection must include the U.S. manufacturing infrastructure. MEL's unique expertise and experience can be used to help define the issues and strategy in this area. Knowledgeable risk analysis of distributed, global, information-based manufacturing systems will help define the research agenda to ensure secure interoperable systems. MEL expertise in hierarchical information architectures and reliable data exchange could support such efforts. MEL should proactively seek participation in NIST-level, interagency, and industrial planning for infrastructure protection. MEL is in a favorable position to coordinate action across the federal/industrial boundary and in related technical aspects of this issue.

While the issue of software vulnerability and secure interoperable systems is one important facet of securing the manufacturing infrastructure, other broader issues exist that MEL might address or at least raise. Examples of areas that need consideration include identification of critical manufacturing technologies and practices that must be protected; the development of robust supply networks, especially those that have overseas components, and understanding of the economic impact of destabilization of these supplier chains; and identification of environmental impact in case of catastrophic events in manufacturing plants dealing with hazardous materials.

Nanotechnology

With its advanced measurement capabilities, NIST has an important role to play in establishing nanoscale measurement methods and standards. To date, NIST's role has not been widely recognized, nor has NIST received a significant amount of the substantial increases in federal investment in this area. The completion of the Advanced Measurement Laboratory at NIST Gaithersburg will give NIST even greater capabilities on this scale, and this event should be capitalized upon by MEL, which has a clear role to play in nanotechnology. This role is a natural extension of MEL's existing competence in metrology, measurement methods, and standards for length. As these are all enabling technologies for the growth of nanoscale industrial processes, the panel hopes to see MEL aggressively pursue its measurements and standards role in nanotechnology research.

Health Care

The MEL role in health care is not entirely clear to the panel. Nonetheless, the size and importance of this sector and the rapid acceleration of technology adoption in medical practice make it worthwhile for MEL to consider what impact it might have in health care. The panel suggests that MEL identify key customers in this area to find out if they have needs that MEL can address and determine the areas in which MEL's contribution could be unique, implementable, and appreciated. MEL should look particularly for those areas in which its capabilities would be complementary to its ongoing efforts, areas such as manufacturing systems interoperability, measurement techniques and algorithms, and standards development. On the basis of these considerations, MEL should decide whether it will try to have an impact in this sector.

Information and Knowledge Management

The panel is enthusiastic about the choice of information and knowledge management as a NIST Strategic Focus Area (SFA). This SFA plays to many of MEL's existing technical strengths, and the panel expects that each division of MEL will contribute strongly to this SFA's objectives. The SFA seeks to enable the conversion of data into usable knowledge, and it can draw heavily on MEL expertise in the architecture of sensing and actuation and the development of related standards. It is not yet clear to the panel how the choice of this area as an SFA will affect NIST's strategy and funding distribution. The panel looks forward to more information and evidence of progress in this area in the FY 2003 assessment.

Laboratory Resources

Funding sources for the Manufacturing Engineering Laboratory are shown in Table 3.1. As of January 2002, staffing for the laboratory included 200 full-time permanent positions, of which 136 were for technical professionals. There were also 27 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

MEL's budget has failed to keep up with inflation for several years. This failure, combined with mandatory salary increases for staff, has meant that the full-time permanent staff of the laboratory has shrunk significantly in the past several years, presenting considerable problems for MEL management as it seeks to address laboratory goals, objectives, and priorities. These problems also appear to be having a negative impact on staff morale, as staff experience the frustration of declining budgets, uncertainty about program futures, and having to spend increasing amounts of their time chasing external funds for their research.

While recognizing the challenge of managing under such difficult resource constraints, the panel believes that MEL could improve the use of its resources through more specific resource planning. MEL progress in strategic planning has not been matched by resource planning. There is need for a resource plan that encompasses human resources, equipment, and facilities and that is integrated with the MEL strategic plan to assure that resources are available for and directed toward the laboratory's highest-priority programs.

In the area of human resources, the panel suggests that MEL adopt a 5-year personnel plan to predict the mix of skills it will need 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

TABLE 3.1 Sources of Funding for the Manufacturing Engineering Laboratory (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	27.9	27.3	29.1	29.7
Competence	1.4	1.1	1.0	0.6
ATP	2.0	1.8	1.3	0.1
Measurement Services (SRM production)	0.1	0.1	0.1	0.0
OA/NFG/CRADA	4.6	6.1	6.1	3.9
Other Reimbursable	4.8	5.1	5.1	4.9
Total	40.8	41.5	42.7	39.2
Full-time permanent staff (total)[a]	239	232	211	200

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.

necessary skill mix is available for the future will help increase the effectiveness of MEL's use of resources and of its programs overall.

In developing a personnel plan, MEL should give particular consideration to the balance between administrative staff and technical staff and also to the balance between managers and bench-level staff. The panel members found the ratio of administrative staff to technical staff to be quite high compared with that of their organizations. Some divisions have already begun reprogramming administrative positions to technical positions as the former are vacated. As administrative positions open up, the panel believes that managers should consider carefully whether those positions' duties can be effectively reassigned to remaining administrative staff and the resources used to broaden or deepen the technical skill base. The panel also noted a large ratio of manager to bench-level staff with the laboratory's current matrix management approach. If the matrix managers are still functioning mainly as scientists, the ratio may not be inappropriate.

The panel is in agreement with the matrix management approach MEL is taking to meeting its programmatic objectives, but it notes the difficulties that accompany implementation of this approach. Frustration has arisen among program managers who are not also group leaders, as well as among the technical staff who report to these program managers. It is not reasonable to expect an employee to work on a project for which he or she is not evaluated. In many cases, the objectives of a group leader, who does have reporting responsibility, are at odds with those of a program manager who does not have line reporting responsibility. In such situations, the technical staff member is given the uncomfortable choice of either supporting his or her group leader and getting a good evaluation or supporting the program leader who has responsibility for achieving specific program objectives.

Such tensions, which are not unusual when implementing a matrix approach, can be significantly ameliorated by appropriate employee performance evaluation. Because some projects cross division boundaries, the MEL director, the division chiefs, and the program managers should all be involved in the employee evaluation process. Program managers as well as group leaders should submit evaluations of all technical staff members working on their projects. Evaluations of group leaders and division chiefs should consider their support of cross-program projects. Such an approach can relieve much of the tension experienced by personnel in a matrix-managed situation. MEL management should consider talking to colleagues at other government laboratories that utilize matrix management (for example, Lawrence Livermore National Laboratory) to see how they implement the matrix approach.

The panel was pleased to see the many instances of internal recognition of staff accomplishments. Such recognition by top MEL management helps build staff morale and can give greater emphasis to laboratory priorities. The panel encourages increased use of internal awards and staff recognition.

Existing equipment within MEL is generally acceptable. However, as the panel noted last year, no detailed plan exists for equipping the Advanced Measurement Laboratory (AML). As this laboratory comes closer to completion, the need for a specific equipment plan becomes more urgent. This plan must detail both the equipment that is to be purchased and the existing equipment that is to be moved and refurbished. The AML offers MEL and NIST the capability to do world-class work in a number of important areas, but this potential will be realized only if the facility is properly equipped. As lead time for the purchase of major instruments can be several years, planning for equipment in this new facility is overdue.

MEL presented the panel with information on NIST's new Organizational Focus Areas (OFAs)—personnel, customer focus, and information technology (IT) infrastructure. The panel applauds these choices; having discussed customer focus above, the panel comments below on personnel and IT infrastructure.

Personnel

MEL's plan in the personnel OFA needs to address the work environment. In particular, to be successful in its matrix-management approach, MEL needs to pay closer attention to the nurturing of staff skills and development. A long-range plan is needed for staff career development. Attention is needed to long-term guest researchers, who are generally overlooked in plans for mentoring, rewards, and advancement but who nonetheless make significant contributions to MEL's research agenda.

This OFA complements the SFA in information and knowledge management. Knowledge management can be used to create a collaborative environment across programs at NIST. By creating, collecting, storing, and sharing data and knowledge, staff can use knowledge from across NIST to achieve results and can create virtual "centers of expertise." The OFA must consider rewards for sharing data and collaborating.

MEL efforts in personnel should include tracking of results to enable continuous improvement in personnel practices. MEL presented the panel with its own internal survey of staff, but the sample size presented and the response received were too small to be meaningful. Additional means of obtaining meaningful data—such as results of the biennial NIST-wide employee survey—should be used to track employee satisfaction in MEL.

IT Infrastructure

An efficient and effective IT infrastructure is vital in any modern organization. This OFA concentrates on reducing IT costs by using a combination of centralized and decentralized approaches to service. The panel did not hear any discussion of the use of collaborative software for managing knowledge and business practices; use of such software could contribute significantly to the OFA goals. Since information- and knowledge-based manufacturing is a major component of MEL's work, MEL is a significant stakeholder in this effort and should be a major contributor to planning in this area.

Laboratory Responsiveness

In its previous report, the panel's primary recommendations with respect to MEL concerned the declining level of staffing, the need for better strategic and program planning, and the need for an equipment plan to ensure future capabilities, especially in the AML. The new MEL director provided responses to all three of these concerns. On the issues of staffing and planning, it is clear that the laboratory is making efforts in the right direction. The remaining issues in both of these areas are matters requiring longer-term attention; the panel will look forward to increased progress in these areas over time. The panel would also like to see metrics that capture progress over longer periods of time, while recognizing that recent changes in management structure make the continuity of such metrics difficult. As noted above, the panel was disappointed to see that no action had been taken on the need for a plan to equip the AML. The time horizon for occupying the AML is growing shorter, and the time at which this planning should have been initiated is already past. The panel urges MEL and NIST as a whole to develop the equipment plan quickly but carefully and to begin its implementation, since the process of refurbishing and procuring the necessary equipment can be expected to take several years. The capabilities of the AML offer NIST extraordinary opportunities to advance measurement science, but these opportunities will be wasted if the facility is not properly equipped.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- The panel concurs with the broadening of the Maufacturing Engineering Laboratory mission statement to recognize manufacturing beyond that of discrete parts. MEL should consider whether its mission should state its role in information technology more explicitly and whether the mission statement should be posed in more proactive terms.
- MEL has made progress in its strategic and program planning efforts. More remains to be done to achieve an integrated plan for MEL efforts at all levels. In particular, the laboratory needs a resource plan that can be integrated with the strategic plan to ensure that MEL will have the skills, equipment, and facilities it needs to meet its intermediate-term goals and objectives.
- MEL has improved its customer focus but needs to continue to work to define its customers better. In particular, to have the impact on manufacturing that it seeks, MEL must broaden its customer focus by looking deeper into the supply chain. It should also consider customers at all levels of the companies and organizations with which it interacts, not just at the level of scientific and engineering peers.
- The panel agrees with MEL's matrix management approach as a means to best utilize staff skills to accomplish laboratory objectives. Changes in the employee evaluation process may be necessary to better align evaluation with the program management structure.

- The panel is concerned about the decline in the number of MEL technical staff and its impact on the laboratory's ability to meet its goals and objectives. The laboratory lacks a human resource plan that anticipates skills needed to meet goals, takes staff retirements and separations into account, and lays out a strategy to ensure that MEL has or can obtain the skills necessary to meet its highest-priority objectives. Careful consideration should also be given to the ratio of administrative support staff to technical staff and to the ratio of managers to technical staff.

DIVISIONAL REVIEWS

Precision Engineering Division

Technical Merit

The mission of the Precision Engineering Division is to provide the foundation of dimensional measurement that meets the needs of the U.S. industrial and scientific communities—by conducting research in dimensional measurements, developing measurement methods, providing measurement services, and disseminating the resulting technology and length-based standards. Within the division is 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 panel is very impressed with the quality of the work and the array of capabilities represented within the Precision Engineering Division. The division performs length measurements over 12 orders of magnitude, all at state-of-the-art precision for national measurement institutes (NMIs). This range is divided into four overlapping segments, corresponding to the groups listed above. Each group has successfully achieved many well-defined goals since the last review in 2001 and is making significant contributions to the overall success of the division. The division's staff continues to perform outstanding work that is recorded 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.

Nanoscale Metrology Group. 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 the reference measurements, reference standards, and metrology necessary to realize the production goal of 100-nm devices by 2005. This encompasses Standard Reference Materials (SRMs) and metrology methods for photomask and wafer critical dimension, pattern placement and overlay metrology, as well as the development of three-dimensional structures of controlled geometry whose dimensions can be traced directly to the intrinsic crystal lattice. The program has been strongly guided by the International Technology Roadmap for Semiconductors (ITRS). Members of the Nanoscale Metrology Group continue to work in close collaboration with the industry consortium International SEMATECH.

Notable achievements of this group within the past year include the development of a process by which the ultrahigh-vacuum scanning tunneling microscope (UHV STM) can write features as small as 10 nm and the completion of studies leading to the construction of a next-generation Line Scale Interferometer. The group also developed a maskless lithography system, completed calibration and delivery of photomask standard artifacts for SRM 2800, fabricated a second-generation overlay test reticle set, fabricated a new scanning electron microscope (SEM) test pattern, and issued SEM Sharpness Standard SRM 8091.

As predicted in last year's report, the division's ability to support semiconductor mask suppliers with meaningful standards is slipping because of the lack of state-of-the-art equipment. In the push to produce 100-nm and smaller wafer feature sizes, the semiconductor industry is relying increasingly on enhancements to mask technology, such as phase-shift masks, proximity correction, and subresolution assist features. Consequently, the dimensional metrology issues associated with masks are expanding rapidly, especially given the role of the so-called mask enhancement factor (MEF) in increasing the sensitivity of wafer dimensions to mask dimension variation. Mask dimensional metrology is an area in which the accuracy issues central to the NIST mission play a critical role. Nonetheless, according to panel members' informal survey of colleagues in industry, U.S. mask suppliers are not utilizing NIST standards as widely as should be expected. The two-dimensional placement standard that they require is not yet available from NIST, and the German standard is used instead. The NIST standard is only slated for release in the fall of 2002. One reason given by the division for the delay is NIST's reliance on the availability of two-dimensional grid equipment at Photronics; hence the need for internal equipment. The uncertainty associated with current optical critical dimension standards from NIST is greater than the 10-nm specification that critical levels require. To its credit, NIST has pioneered work in reducing line edge roughness, a significant contributor to measurement uncertainty. Mask makers are increasingly turning to SEM metrology to control and validate their manufacturing. In the absence of state-of-the-art SEM capability, NIST is not in a position to support their needs.

Surface and Microform Metrology Group. The Surface and Microform Metrology Group works primarily in the measurement of nanometer- to micron-scale surface features, utilizing microscopy or stylus-based instrumentation. Several areas of the division's work support areas of industrial interest, such as microelectronics, optics, other manufacturing industries, and homeland security.

Most projects target a specific need and are focused. However, the group seems to lack an identity and has been driven to simply "go where the money is," rather than to remain focused on its core competencies and charter. Specific projects have led the group to work more in the nanoscale than in the traditional micrometer-scale work that remains important to industries such as the automotive and aerospace industries. This tendency may also be driven by the equipment and staffing of the group, which are better suited for nanometer work. In micrometer surface metrology areas, particularly stylus-based measures, primary customers are metal-cutting industries. These more traditional industries, because of years of optimization and cost reductions, do not often have the budgets for research. However, in terms of the manufacturing economy, they still require ongoing support.

Staff members in the Surface and Microform Metrology Group are highly regarded in the technical community, and their work is world-class. In some cases, however, the NIST instrumentation is lagging behind what is currently available in industrially based laboratories. As a result, the group is sometimes forced to choose projects primarily because of the instrumentation available rather than for strategic reasons.

Engineering Metrology Group. The Engineering Metrology Group works to manage and reduce the contribution to uncertainty of the traceability of length, location, and spacing measurements as well as other traditional geometric, dimensioning, and tolerancing dimensional controls (roundness, cylindricity, perpendicularity, angle, and so on). The group characterizes, evaluates, and improves instruments that measure length and coordinates, and it develops new measurement techniques for measurements from

1 micrometer to about 1 meter. This group also supports the availability of alternate routes to establish traceability, such as National Voluntary Laboratory Accreditation Program (NVLAP) laboratories (for example, the Oak Ridge Y12 Metrology Laboratory and the Starrett-Webber Gage Block Laboratory) and other ISO-17025-compliant laboratories, as well as collaboration with other recognized NMIs such as the National Physical Laboratory of the United Kingdom and Physikalisch Technische Bundesanstalt of Germany. The group's primary customers are the U.S.-based discrete-parts manufacturing industry and the measurement equipment makers that serve them (such as those affiliated with the American Measuring Tools Manufacturing Association).

Because of collaborations with measurement equipment makers that have provided necessary instruments to update several key measures, the group's equipment is up to date relative to that used by its customers. The group has achieved world-leading status in length traceability and evaluation of two-dimensional coordinate measurement machine (CMM) artifacts through the use of an M48 Moore Special Tool CMM with Brown & Sharpe control and analysis software and systems. This capability is world leading at 1 micrometer error or less anywhere in the artifact volume. The advanced automated master angle calibration system (AAMACS) polygon calibration system is also of world-leading status in technology and capability. 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 at that level.

A reasonable amount of research is being done to support the discrete-parts manufacturing and measurement equipment makers' current and future measurement needs. The projects include these:

- Research in collaboration with NIST Boulder to decrease the uncertainty of laser interferometry measurements for greater capability in length and frequency metrology,
- Research in dilatometry to measure thermal expansion with lower uncertainty and carry the capability to two-dimensional grid expansion,
- Cylindricity capability research in collaboration with industry,
- New laser micrometer methods for measurement of sperical and cylindrical diameters, and
- New probing methods for submillimeter feature measurement and for use in new calibration methodologies.

The Engineering Metrology Group also is continuing to support the research and standardization of uncertainty management. It supports the Shop Floor as NMI Program, which seeks to provide documentary standards and to educate industrial users about how to manage measurement uncertainty. In all projects the group endeavors to include studies in levels of confidence in its measurement developments and services. Collaboration with international NMIs is ongoing to compare group results with those of its international colleagues.

The group's services will be shut down around 2004 for several months in order to 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.

Large-Scale Coordinate Metrology Group and Shop Floor as NMI. The Large-Scale Coordinate Metrology Group works to characterize, evaluate, and improve instruments that measure lengths and coordinates greater than 1 m. Originally the group considered mostly fixed CMMs, but today it looks increasingly to a wide variety of portable CMMs. Some of the group's projects are partly funded by outside grants and contracts. These include the development of a laser-rail calibration system for laser trackers and a total-station measurement system for shipbuilding. One of the group's important goals, is the development of measurements and simulations that help in the calculation of measurement uncertainty. In addition, Chebyshev referenced algorithms and rigid-surface fitting algorithms are being created for industry's self-assessment of measurement and will be placed on the Web site. The members of the technical staff hold many leadership positions in professional organizations and standard-setting groups.

The Shop Floor as NMI Program aims to help U.S. parts manufacturers support their claims of measurement traceability, even without a direct NMI dimensional calibration, by providing documentary standards, guidelines, and reports. Several of these documents were completed this year; one was recognized as the best paper of the 2001 International Meeting of the National Conference of Standards Laboratories. The program is also undertaking projects to help instrument users characterize uncertainties in shop-floor measurements. Projects include the development of a smart artifact (a calibrated artifact that serves as a surrogate workpiece, containing advanced GD&T features); a ball-bar calibrator; a method for fitting complex surfaces; and a method for estimating thermal distortion. In response to last year's report, the program has been reduced in size, and the new projects are focused on goals having greater applicability and impact.

Program Relevance and Effectiveness

Technical professionals and lower-level managers in the Precision Engineering Division have good contacts in industry and academia. At the project level, strong interactions with customers and contributing professionals outside of NIST contribute to the relevance and effectiveness of the individual projects. The involvement of high-level division and MEL management with customers and industry leaders is not apparent, however, and individual programs seem to be left on their own to define and carry out their goals. While some benefits accrue to a bottom-up approach, it also leads to an inability to formulate a broader strategy that might provide the basis for better program direction and a stronger funding outlook.

The division's current attempts at quantifying goals in terms of time, money, or savings are erratic. For example, last year the Surface and Microform Metrology Group articulated the goal of saving industry $80 million over the next 5 years. This year, no mention was made of that goal or of progress toward it. The panel does not mean to suggest that all programs should be driven by potential savings to industry, particularly since such numbers are often hard to validate. Where meaningful, however, the quantification of benefits is essential to tracking progress and to establishing priority among many possible tasks. It is also a powerful tool for marketing the division—both to improve the visibility of its programs to industry and to solicit industry funding for critical expenditures.

The division's setting of goals and reporting of progress would be improved by adopting methods more consistent with those used in industry. Progress reports too often consist of a recitation of technical details without any perspective on performance trends over time. Reporting would be more effective if the division used conventional methods that enable rapid assimilation and comparison of results. For example, SRM introduction could be tracked using time-to-introduction Gant charts, and measurement services could be tracked by year-to-year volume, revenue, and cost.

The division is effective in communicating with customers via publications and conferences, and its Web site contains a wealth of information. In many cases, programs respond to specific customer requests, but the division does not appear to track customer usage of its results. An informal survey of colleagues conducted by panel members revealed significant doubts and misconceptions on the part of potential customers regarding the relevance of NIST results to the semiconductor industry.

The Engineering Metrology Group and its resources are heavily used by its customers, with many customers relying on the group's services. Among all of the MEL groups, Engineering Metrology has the highest level of income from services ($800,000 in calendar year 2001), making most of its calibration services self-supporting. The group has also received equipment from industry to use to push the state of the art in several areas, which demonstrates strong trust, collaboration, and rapport with this customer segment. Thus, the group seems to have a clear picture of its area of responsibility and its duties to satisfy customer needs. However, the group is struggling to reduce calibration costs, which are due in part to rising overhead rates. It is difficult for the group to provide any calibration for less than $5,000, and this level of cost pushes customers to use alternate routes such as National Voluntary Laboratory Accreditation Program (NVLAP) and ISO 17025 laboratories.

The Engineering Metrology Group has good customer relations, but it could establish stronger ties to discrete-parts manufacturing customers by communicating its capabilities, desired research directions, and ongoing developments. The group might be able to bring in more industry money and backing to support such work. Participation in consortia, standards committees, and trade shows could be used more widely to inform, receive feedback, and solicit support.

Division Resources

Funding sources for the Precision Engineering Division are shown in Table 3.2. As of January 2002, staffing for the division included 35 full-time permanent positions, of which 32 were for technical professionals. There were also 5 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Funding levels and staffing appear to have stabilized over the past year. As a result, staff morale has improved. Retention has also improved, no doubt in part due to the decrease in attractive high-tech opportunities elsewhere.

TABLE 3.2 Sources of Funding for the Precision Engineering Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.8	6.1	6.9	7.0
Competence	0.6	0.4	0.4	0.0
ATP	0.4	0.2	0.3	0.1
Measurement Services (SRM production)	0.1	0.1	0.1	0.0
OA/NFG/CRADA	0.7	0.8	0.9	0.4
Other Reimbursable	0.8	0.8	0.8	0.8
Total	8.4	8.4	9.4	8.3
Full-time permanent staff (total)[a]	42	41	36	35

NOTE: Sources of funding are as described in the note accompanying Table 3.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

Underlying the division's lack of capital planning is its lack of strategic planning, also raised in the recommendations of the past 2 years.[3,4] Significant capital purchases cannot be justified without a comprehensive plan showing that they are necessary to meet critical program objectives. This strategic plan must be based on close engagement between NIST upper management and the customer community.

Despite the high technical capability and progress demonstrated, the Nanoscale Metrology Group's programs suffer from lack of state-of-the-art metrology equipment to provide meaningful industry support in the nanometer regime. This deficiency was noted in last year's report. Both NIST researchers and industry customers have identified two critical equipment needs: (1) a current-generation critical dimension-SEM (CD-SEM) for dimensional metrology for both masks and wafers and (2) a nanometer-scale two-demensional grid metrology system. NIST acquisition of a combined SEM/focused-ion-beam tool for the in situ cross-sectioning of masks and wafers would support this rapidly growing area of metrology activity in the semiconductor industry. All of these are "big-ticket" items, each costing upwards of $2 million to $3 million. Existing funding strategies do not allow such capital purchases. In fact, MEL management recently rejected a proposal that would have had SEMATECH fund much of the cost of a new CD-SEM. The division's lack of advanced metrology equipment is already hampering its efforts to support industry. Given that nanotechnology has been identified as a national initiative and a NIST Strategic Focus Area, NIST management must find ways to enable the acquisition of these essential metrology tools. Providing to industry metrology services that are enabled by new equipment, perhaps modeled after the services provided by the Engineering Metrology Group, could at least partially fund the equipment.

As stated above, the equipment budget allocated for the Advanced Measurement Laboratory appears inadequate. Furthermore, division researchers have apparently not been actively engaged in planning equipment purchases for the AML facility, although they plan to migrate important programs there. If AML occupation is going forward in 2004, equipment planning is already overdue. The panel is concerned that the division may not be able to make full use of the AML's capabilities for lack of appropriate equipment.

Funding continues to be an ongoing battle for the Surface and Microform Metrology Group. It is very difficult for the group to initiate a new project or program with its own funding, and few customers for this area are willing to provide significant funding. This lack is also evident in terms of the age and capabilities of NIST instrumentation compared with industry capabilities. Many of the group's instruments, while they are well understood and well utilized by the staff, are not up to date; SEM calibration is one example—NIST cannot produce an artifact that is needed by industry because of the lack of instrumentation necessary to calibrate it.

Manufacturing Metrology Division

Technical Merit

According to division documentation, the mission 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 the following:

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[3]National Research Council, *An Assessment of the National Institute of Standards and Technology Measurement and Standards Laboratories: Fiscal Year 2000,* National Academy Press, Washington, D.C., 2000, p. 69.

[4]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, p. 82.

- 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 name of the division—Manufacturing Metrology—implies a broad scope of activities related to manufacturing. The mission also can be interpreted as being quite expansive. Recognizing the limitations of budget and number of personnel, the division's 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. The division also plays a supporting role in other programs—Nanomanufacturing, Shop Floor as NMI, and Nanoscale Metrology. The panel commends the division for focusing its scope 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.

Overall, the Advanced Optics Metrology, Mechanical Metrology, and Smart Machine Tools Programs are well focused on areas of significant need and are of high technical quality. The panel was particularly impressed with the Advanced Optics Metrology Program, which addresses an area of significant need in semiconductor manufacturing and appears to be well connected with users through International SEMATECH. The panel has some concern regarding current program leadership in Advanced Optics Metrology. As a result of staff turnover, the division director has assumed the role of interim manager of this program. The panel hopes that the division will use this opportunity to recruit someone with strong technical as well as managerial skills to lead this important program.

In response to the previous panel review, the division significantly altered its Smart Machine Tools Program. In fact, this program has changed titles, and the scope of the program is now very well defined. The critical technical issues have been identified, and the team has established a preliminary road map for projects appropriate for NIST. The panel believes that the road map for this program should continue to evolve, as it is not yet fully developed.

The panel believes that the goals of the Predictive Process Engineering Program, which is only partially supported by the division, are admirable, but they are not new and likely not realizable. The panel commends the program leaders for responding to last year's recommendation to narrow its scope. As a result of that action, the integration of projects within the program is better defined, and the program focuses on just two metal-cutting operations. However, despite this restricted scope, the panel remains concerned about the complexity of the total integration of all the subprojects and believes that the program's focus is still too broad and that its stated goals are unattainable. The panel also believes that the program's efforts on process models are misplaced and should be focused instead on manufacturing software interoperability and standards, which would be more in line with NIST's mission and expertise. The panel recommends that in the coming year, the group select a demonstration part that each project in the program can utilize, integrate the available simulation models, and thus focus and link all the important technical project deliverables essential for fulfilling the program vision. Doing so will highlight the technical capabilities of the concept, and any unforeseen technical challenges will be exposed. The panel thinks that the demonstration part will be critical for tracking the ongoing progress of the projects and the overall program. The panel recommends that after the demonstration part is completed, the division seriously reevaluate its available technical resources for this program, and, if necessary, secure the appropriate expertise to meet revised program goals.

The panel continues to be impressed with the division's work on microforce measurements. This team has made significant progress in the past year, and the panel believes that the effort exemplifies the type of work in which NIST should be engaged.

The continuing role of the division as a leader in the development of national and international standards ensures that U.S. interests 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[5] signed in 1999 by the NMIs of the 38 member states of the Metre Convention. The division's continued active role in this area is imperative.

Program Relevance and Effectiveness

The Manufacturing Metrology Division serves two primary roles. First, the division is the nation's reference laboratory for the units of mass, force, vibration, and sound pressure. In this role, the division serves the nation by providing calibration services, developing advanced methods for mechanical metrology, developing national and international standards, and leading efforts with international standards organizations. This role is critical for the nation's manufacturing industry, and it is also critical 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. Given limited technical resources, the division has decided to phase out its ultrasonic standards work. While this may alleviate the shortage of resources in the near term, the long-term implications of the reduction of measurement and standardization capability cannot be predicted, particularly in view of NIST's stated intent to play a role in health care.

The second major role of the division is to develop manufacturing and mechanical metrology technology. The customers of this effort include both industrial and governmental communities. The division fulfills this role through its own 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 workshops, consortia, and standards committees. Workshops are also used to identify customer needs. Division staff are frequently invited speakers at conferences and seminars. These presentations, the issuance of standards, and the division's technical publications all provide evidence that the division is serving its customers, although these indicators cannot be used to measure the impact of these results quantitatively. The impact of calibration services is more readily determined by considering the number of paying customers. A user survey by the division indicates that the customers for these services, while concerned about costs, are satisfied. A clearer indication is achieved by the Mass and Force Group, which 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 [American National Standards Institute/American Society of Mechanical Engineers] standards, and international standards) also indicates the relevance of the division's work.

Toward the beginning of calendar year 2001, the division introduced a matrix-management structure utilizing group leaders, program managers, and project leaders. Though matrix management has been very successful in large organizations with several distinct cross-functional responsibilities, the

[5] International Bureau of Weights and Measures, *Mutual Recognition of National Measurement Standards and of Calibration and Measurement Certificates Issued by National Metrology Institutes,* International Bureau of Weights and Measures, Paris, France, 1999.

panel wonders whether the same benefits are being realized in this division because of its smaller organization with rather homogeneous responsibilities. The panel believes that the transition to the matrix-management structure has created some unnecessary and costly duplication. Specifically, the panel wonders whether the roles of the Mass and Force Group leader and the Mechanical Metrology Program leader might be filled by just one individual, thus freeing up one person for other assignments. From a discussion with bench-level researchers, the panel found that the new management structure has led to considerable frustration as researchers attempt to "serve two masters" (group leaders as well as program managers). As a result, the researchers are experiencing work insecurity and inefficiency. Also, the perception exists among the researchers that employee reviews are not adequately coordinated between group leaders and program managers, although the panel heard that the management team tries to collaborate on these reviews. Group leaders appear to find the new management structure awkward at times but are trying to make it work. They find it a challenge at times to match employee skills with research needs. The panel believes that while matrix management may be beneficial for the division, its implementation should be continually monitored and modified as necessary to ensure that the hoped-for results are realized at all levels. Supervisory training is especially important during the transition to matrix management, as is the need for increased communication at all levels of the organization.

The panel heard little discussion of project selection criteria in this review, as was also observed in last year's report. This 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

Funding sources for the Manufacturing Metrology Division are shown in Table 3.3. As of January 2002, staffing for the division included 40 full-time permanent positions, of which 36 were for technical professionals. There were also 5 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

TABLE 3.3 Sources of Funding for the Manufacturing Metrology Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.4	5.6	5.6	5.7
Competence	0.4	0.3	0.3	0.4
ATP	0.3	0.3	0.5	0.0
OA/NFG/CRADA	1.2	2.0	1.5	0.9
Other Reimbursable	1.3	1.2	1.2	1.0
Total	8.6	9.4	9.1	8.0
Full-time permanent staff (total)[a]	44	46	42	40

NOTE: Sources of funding are as described in the note accompanying Table 3.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

The panel is deeply concerned about the division's ability to retain talented technical professionals and to recruit equally talented new employees. Several technically strong, key personnel left the division in the past year. The success of the division's programs relies heavily on the technical competence of its staff. The division now has a small number of researchers covering many technical areas, which can negatively affect program results. Strong fiscal constraints appear to preclude new hires.

The panel commends the division for its renewed efforts to augment the permanent staff with postdoctoral fellows but is concerned that if the number of topflight researchers who might serve as mentors declines, the goal of increasing the number of postdoctoral researchers will become difficult to realize. In a meeting with the panel, division staff voiced concerns over budget, time allocation, the matrix-management system, and scarce resources. All these issues are of concern and affect staff morale.

The division's technical resources have been flat or declining over the past several years. The panel recommends that the division explore cost-effective ways of expanding its technical capabilities, such as giving critical consideration to a significant reduction of its nontechnical staff. This may represent the only real opportunity for the division to develop its technical capabilities without adding to the total number of staff members.

Intelligent Systems Division

Technical Merit

According to division documentation, the mission of the Intelligent Systems Division 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. The division manages Intelligent Open Architecture Control of Manufacturing Systems, Intelligent Control of Mobility Systems, and Critical Infrastructure Protection Programs. It also supports Predictive Process Engineering, Shop Floor as NMI, and Nanomanufacturing Programs. The division manages a Competence Development project, which extends basic research that was formerly part of the Research and Engineering of Intelligent Systems Program.

The Intelligent Open Architecture Control of Manufacturing Systems Program continues important work related to easing the problem of interoperability of manufacturing hardware systems. It has a goal of developing a suite of standards in this area by 2005. This is clearly an area in which the division can have significant impact on industry through the promulgation of standards for intelligent systems. The program comprises work on a number of standards and on testing and validation of standards for several different industries and equipment types: for example, standards for machine tools, motion control in general, robotic welding, automated inspection, factory robots, CMMs, and so on. The program has performed a number of demonstrations on tasks ranging from integrated metrology systems to welding control systems. It is currently developing a metrology testbed, in part to test standards for automated inspection and inspection data handling. The program has also made progress on the use of open systems; the panel was particularly interested in the promising work on the real-time use of Linux in control systems. One of the most mature projects involves the Standard Exchange of Product data standard for computer-aided design and manufacturing (CAD/CAM applied to numerical control [STEP-NC]). While STEP-NC has been demonstrated to allow sharing of data among systems, differing interpretations of the standard can result in machined parts that differ from their intended design. To prevent this, the division is developing conformance tests for CAM system and machine tool controller adherence to STEP-NC. This effort involves both virtual and solid model comparisons, development of measurement artifacts, and physical measurements.

The goal of the Intelligent Control of Mobility Systems Program is to satisfy the measurement and standards needs of U.S. industry and government agencies in developing and applying intelligent control technology to mobility systems in order reduce cost, improve safety, and save lives. The program consists of three projects: Industrial Material Handling, DOD Unmanned Ground Vehicles (UGV), and Performance Measures for Mobile Robots. A significant portion of the 2001 expenditure on this program ($3.5 million out of a total of $4.0 million) was obtained from other agencies. The division participated in the Army Research Laboratory's Demo IIIC, providing the control systems architecture, advanced sensor systems, and standards to achieve autonomous mobility for unmanned vehicles. The demonstration was very successful, and a significant level of further funding is expected—which evidences the leadership status of the division in this area. It is among the world leaders in this technology.

The division responded to the need of the U.S. search-and-rescue community to develop and disseminate reference test arenas to enable measurement and understanding of robot capabilities. The test course designed by the division was adopted by the American Association for Artificial Intelligence conference in 2000. NIST will chair the RoboCupRescue competition in 2002 in Japan. The division has used funding from other agencies (OA) in advanced robotics projects to remain at the forefront of research in the autonomous control of complex systems, and it has invested direct appropriations to transfer advanced robotics technology to manufacturing applications. For example, a project on the vision guidance of robots that handle industrial materials attempts to demonstrate and transfer the DOD UGV technology to industrial applications. It utilizes a conventional vision camera to track double lane markers along its desired path, a configuration typical of aerospace facilities. The panel is pleased with the division's technology transfer effort. At the same time, the panel notes the need to objectively assess the difference, if any, between military problems and manufacturing problems. The division's focus should be on adapting its technology, that is, ladar guidance in an unstructured environment, to provide advantages in the industrial environment, rather than on applying its resources to solve a specific user need with conventional technology.

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 utilities, processing industries such as oil and gas, chemicals, pharmaceuticals, metals and mining, and pulp and paper, as well as consumer products and discrete-parts manufacturing industries. The program has the objectives of defining and applying standard information-security requirements, developing best practices for information security, and developing laboratory and field-test methods for information-security products applied to the process control sector. The division has rationalized the criticality of this program by identifying typical sources of vulnerability in process control systems, historically isolated but now increasingly connected to outside information and communications networks. Furthermore, the changing controls and customer support technologies often enable outsiders to gain access to process control systems through wired and wireless communications systems, which appreciably increases an enterprise's vulnerability to hackers and destructive interference. The criticality of the program is further underscored by the potential consequences of attack in terms of loss of life and production, endangerment of public health and safety, social disruption, and environmental damage.

The division has followed a pragmatic approach to managing the Critical Infrastructure Protection Program by forming the Process Control Security Requirements Forum, with representation from related industries, concerned government and private agencies, and other relevant NIST divisions. The forum'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. This goal is well aligned with the division's goal. The testbed identified for testing of proposed protection products is simple and adequate, and it appears to be expandable so that it can accommodate new elements as they are recognized. A task list has been developed for FY 2002, with specific tasks related to the core goal. The tasks appear to be chosen as the basis of a structured approach to attain the goal, though no overall plan is obvious. A high-level plan would be valuable, with a road map leading from the current state of vulnerability to the desired state of protection. This road map should include definite dated milestones associated with available funding and resources.

The panel agrees with the approach utilized to support the Critical Infrastructure Protection Program. NIST, through the Intelligent Systems Division, is a natural lead entity for such a critical program. Because the program requires diversified resources not necessarily present at or appropriate to NIST and since it requires the active participation of many proficient and highly specialized resources from private industry and other government agencies, the panel believes that the division should assume leadership in the capacity of a program manager. The division may develop an overall plan and a program strategy, align and assign contracts, manage the budget, test and evaluate the results, and develop the standards necessary for identified security measures. Of particular importance is leveraging existing expertise in system vulnerability identification (white-hat hacking) to identify weaknesses and recommend remedies. The panel recommends that the division acquire such expertise for the execution of this program.

The Competence Development project encompasses the core research themes that were formerly included in the Research and Engineering of Intelligent Systems Program. The goal of the project is to provide the fundamental research underlying the intelligent systems that support the evaluation, specification, and integration of systems applied to manufacturing and other applications.

This project continues the division's long-standing commitment to the development and application of a hierarchical intelligent-systems architecture. This framework and its history are presented in a recently published, comprehensive overview by Albus and Meystel.[6] This book is an important milestone for the project, as it assembles the conceptual basis of this architecture of intelligent control in a form that will support new applications and encourage the comparative analysis and integrated implementation of these concepts.

The NIST real-time control system (RCS) hierarchical architecture forms the basis for applications programs in the Intelligent Systems Division, including manufacturing, open architecture, interoperability, and critical infrastructure. The architecture provides a framework with explicit model hierarchies that integrate sensing. The resulting applications may serve many customers, ranging from the academic and industrial research community to manufacturing and defense industries. The division strategy in this area, which is sound and working well, bases diverse applications on a common architecture. The division must view the architecture as an umbrella for integration rather than as a rigid template. It has the opportunity to further increase its partners and collaborators in this development. Flexibility that enables adopting new concepts within the RCS framework will be important, since new methods for adaptivity and behavioral systems may become modular components of the more general hierarchical system.

A principal strength of the Competence Development and Infrastructure Program is the division's capability to implement and evaluate RCSs in several different applications domains. This experimental

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[6]J.S. Albus and A.M. Meystel, *Engineering of Mind: An Introduction to the Science of Intelligent Systems,* Wiley, New York, 2001.

prototyping approach is unique and important in research programs in robotics and automation, and it should continue to be an area of emphasis in the structure of the research programs. Current projects stimulate fundamental research and analysis through the evaluation of performance in real systems, and they also directly influence and disseminate practical solutions to industrial and government users. The division should continue this role of implementation and evaluation and not be drawn too strongly into pure analysis and algorithm development. Partnerships with academia and other basic researchers can provide the fundamental research support, while the division programs retain a broad capability to integrate, explore, and evaluate new approaches. This program is essential to the pursuit of division goals. The program goals are appropriate and well conceived, but implications of the program may actually be broader than stated, with applications in industries beyond manufacturing. The principal program themes should be examined to emphasize those in which key progress and milestones will be achieved. Alternative themes that align with key domain areas (such as software development and security issues) could be considered, while more abstract themes (such as learning, knowledge engineering, and hybrid control) may be contracted to research partners. The fundamental strength of the division in implementing and evaluating real systems through prototypes and testbeds should be emphasized.

Program Relevance and Effectiveness

The Intelligent Open Architecture Control of Manufacturing Systems Program has had numerous ties with industry, most notably with automobile manufacturers and their suppliers. However, the division's key industrial partners or customers are currently industry groups such as Open Modular Architecture Control, the Robotics Industry Association, the Automotive Industry Action Group, the Metrology Automation Association, the American Welding Society, and the Consortium for Advanced Manufacturing International. These may not be the best sources of information, as they often lack a strategic cross-industry view of the problem. The division has for several years quoted figures of the cost to industry from the lack of interoperability—for example $200 million to $400 million lost per vehicle program, 100 staff-years for each $10 million in capital expenditure, and even costs as high as $1 billion per year for the automotive industry supply chain. In the panel's judgement, these figures are highly credible, which makes the program especially relevant, with great potential for realizing economic and competitive advantages for U.S. industry. However, the panel thinks that if the need is this great, the division's efforts should be larger and more unified than they now appear. Also, a push for this technology from the highest level of industry is lacking, despite its strong cost drivers, suggesting that more outreach to high-level corporate officials is needed. While the goals for the program are reasonable and useful, they will result in a number of rather specific niche standards. More general schemes that can be applied to a broader set of equipment and industry segments would be more useful and more appropriate. The new reality of major industries such as the automotive and aerospace industries is that they are quickly becoming a highly dispersed but even more tightly integrated supply chain that needs to share ever-more-detailed information. The importance of interoperability will be growing even stronger in this atmosphere. It is imperative that this program stay ahead of this trend, and it is recommended that an effort to work with higher-level industry representatives concerned with the longer range be considered.

The primary customers of the Intelligent Control of Mobility Systems Program are the Army Research Laboratory, the U.S. Department of Transportation (DOT), and DARPA. Those customers provide funding for the continued support of this program. The DOD UGV has been a demonstration testbed for the NIST RCS architecture and real-time sensing and measurement. The enormous potential saving of both cost and human life, and the potential safety improvements justify research on UGV for military applications. The division also has a project on side sensing for vehicles, sponsored by DOT. Intelligent transportation systems (ITSs) remain one of the most important technologies, and the project is relevant not only to DOT but also to the automotive industry. The panel recognizes the division's effort to transfer the UGV technology for military applications to manufacturing problems, though industrial customers are yet to be identified.

The Critical Infrastructure Protection Program is a timely and critical assignment for the Intelligent Systems Division. The division is the natural leader for program management and for funding and mobilizing the expertise of proficient and specialized private resources and concerned government agencies. The division has made excellent progress in identifying the problems to be addressed and involving potential funding agencies.

The Competence Development project focuses on four principal themes: performance metrics, knowledge engineering, architectures and tools, and learning. The division has coordinated the development of metrics through an annual conference, Performance Metrics for Intelligent System (PerMIS), that attracted significant participation from the research community in 2000. PerMIS can also serve as an important forum for further discussion of related architectures and concepts that address the challenges of intelligent-systems development. Work in the area of architectures and tools has also progressed well, as demonstrated by the dissemination of RCS architecture for applications to both manufacturing and mobile robotic systems. Collaborations and subcontracts have engaged additional systems users. Strong participation in the DARPA mobile autonomous robot software program has resulted in impressive demonstrations of RCS architecture in mobile autonomous vehicle systems. Advances in knowledge engineering and learning are less convincing, considering the work presented. There are several themes of conceptual work, but the panel heard little discussion of new and unique contributions or applications.

Division Resources

Funding sources for the Intelligent Systems Division are shown in Table 3.4. As of January 2002, staffing for the division included 33 full-time permanent positions, of which 31 were for technical

TABLE 3.4 Sources of Funding for the Intelligent Systems Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.9	5.9	6.2	6.1
ATP	0.5	0.3	0.3	0.0
OA/NFG/CRADA	1.5	2.0	2.9	1.3
Total	7.9	8.2	9.4	7.4
Full-time permanent staff (total)[a]	42	38	36	33

NOTE: Sources of funding are as described in the note accompanying Table 3.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

professionals. There were also 11 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Division personnel are highly qualified, and they express motivation and confidence in their management. The division is privileged to have the only NIST fellow in MEL, benefiting from his contribution to the division's technical objectives.

The panel supports the division's decision not to constrain its research to technologies using computing power available at low cost, and to assume that, when these technologies mature, the computing cost for targeted practical applications will likely be economical.

Because of the large effort and highly specialized expertise necessary for the Critical Infrastructure Protection Program, the panel advises that the division leverage its expertise with outside contracts and focus on program management, funding, evaluation and testing and on developing evolving standards. It is advised that the division add to the program team a resident expert in the identification of system vulnerability. Otherwise the division appears to be properly staffed and funded to support its programs.

Manufacturing Systems Integration Division

Technical Merit

The stated mission of the Manufacturing Systems Integration Division is to promote economic growth by working with industry to develop and apply measurements and standards that advance the use of information-based manufacturing technology. As noted in last year's assessment report, this mission is very encompassing and is not likely to be met without significant internal and external cooperation. But, based on the site visit, the panel believes the wording of the division's mission may be interpreted to mean, "promote economic growth by working with industry to define, refine, and drive interoperability standards for software used in all aspects of manufacturing." If this is an appropriate restatement, division focus on the interoperability of both product and process models becomes an achievable goal. The interoperability focus becomes immediately important (i.e., in the 5-year horizon) and will energize the division in the right direction. The panel suggests developing a divisional strategy to facilitate internal communications, external communications, and the assessment of improvements.

The division is organized in four groups: Design and Process, Enterprise Systems, Manufacturing Simulation and Modeling, and Manufacturing Standards Metrology. The work of the division supports five programs:

- Product Engineering, which includes projects in parametrics exchange, design-analysis integration, assembly and tolerance representation, heterogeneous material representation, and knowledge representation for next generation CAD;
- Predictive Process Engineering, which includes projects in process metrology, representation, modeling, and application;
- Manufacturing Simulation and Visualization, which includes projects on distributed manufacturing simulation environments, and manufacturing simulation transactions and simulation templates and model formats;
- Nanomanufacturing, 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 testbed, and self-integrating system.

Other projects are grouped under the title Special Activities.

The division has recently undergone a major realignment of programs, leading to significantly improved performance. Division management has faced a monumental task in reorienting division activities. The division has much experience and expertise in mechanical engineering and manufacturing, but the industry needs assistance in the areas of formal specifications, semantic representation, knowledge-based systems, ontologies, and software conformance. These emerging areas are still a challenge even to computer scientists, and additional complexities arise when these areas are applied to manufacturing and engineering. The mechanical engineering and manufacturing knowledge and experience of the NIST scientists in this division are highly essential for success in systems integration. The key question is how to train existing personnel and attract new people who can bring the latest, newest technology into the group, especially in this time of flat budgets.

The division is engaged in work at several levels of abstraction in systems integration capabilities, ranging from standards and measurements, to process representation, through integration and modeling capabilities, to the use of software to enhance manufacturing performance. Within this framework, the panel identified two fairly specific technical areas as the foundations for the division's efforts:

- *Interoperability*—Semantic models and knowledge representation methodologies for manufacturing interoperability, for product and process modeling and simulation, and for enterprise integration.
- *Metrology*—Measurements and testing with (1) algorithm testing and evaluation (e.g., looking at variability in physical measurements due to the nature of the software used in the measurement capability), and (2) optical measurement systems to be used for manufacturing at the nanoscale.

Most programs, except Nanomanufacturing, fit this categorization. The programs and projects that focus on interoperability and on metrology and standards are certainly of high quality, have state-of-the-art technical content, and are staffed by highly competent scientists and engineers. In addition, there appears to be a potential for a significant impact on commerce and the economy. Activities reflect both the immediate industrial testbed needs and the longer-term research needs.

The objectives of the Nanomanufacturing Program are not yet clearly articulated. Even so, the panel encourages this multidivisional activity, since the program is in a new and emerging area of technology, and it is wise to consider manufacturing early in any engineering activity. The panel suggests only that, as the division proceeds to work in this domain, it continue to focus resources on the conformance and interoperability issues rather than on instrumentation or basic physics.

For the most part, the division's technical work is of high quality and is carried out with zeal and enthusiasm. However, most programs still have too many activities, and the participating workforce appears to be spread too thin. Unless the division gets more funding, the number of activities will have to be reduced. It seems unreasonable to expect that a staff of relatively constant size can be expected to cover an exponentially increasing domain of needs without loss of quality.

The panel found work on evaluating and certifying software manufacturing coordinate metrology to be an extremely interesting and novel approach to the problems associated with metrology and software certification. The panel strongly encourages continuation and expansion of this unique concept and program.

Program Relevance and Effectiveness

The panel applauds the care taken by the Manufacturing Systems Integration Division to ensure technology transfer. In this regard, the division's leadership in STEP over many years is to be commended. Indeed, without NIST support, STEP would likely not exist.

The Manufacturing Simulation and Visualization Program is doing very commendable work. However, the panel believes that more attention should be paid to "best in class" work outside NIST when determining what should be done within NIST. The panel also suggests that team members solicit the active participation of constituencies in the prioritization of new activities in order to ensure their relevance. This may be done by workshops, site visits, collaborations, seminars, or other similar mechanisms.

Testbed infrastructure development has been recognized as the most immediate, fundamental mechanism for serving constituencies. It would be appropriate to identify performance measures up front for the short-term impact of testbed activities and for the longer-term impact of the NIST semantic testbed.

The panel thinks that the division could increase its dissemination of results through the Manufacturing Extension Program. This program provides the division with a unique opportunity to reach important portions of the supply chain across the country.

In order to maximize its influence, the division needs to issue a clear statement of objectives against 1-year, 2-year, and 5-year time lines. Each program needs to articulate succinct, meaningful, measurable, and significant deliverables within this framework.

Enterprisewide interoperability is a key need, but it is not clear to the panel which constituency will be satisfied by the current research activities in the Manufacturing Enterprise Integration Program. Even after the complete reorganization of this program during the past year, its objectives and scope are not clear to the panel. Because enterprise integration is such a large area, the program should focus on some specific customer's needs—small manufacturing enterprises, for example—rather than on trying to solve the entire spectrum of needs.

Division Resources

Funding sources for the Manufacturing Systems Integration Division are shown in Table 3.5. As of January 2002, staffing for the division included 30 full-time permanent positions, of which 23 were for technical professionals. There were also 5 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Division funding is flat, and total funding is projected to be lower in FY 2002 than in FY 2001. Permanent staff has decreased significantly during a time of unprecedented expansion of the manufacturing domain. The majority of division researchers are nonpermanent staff. Both staff members and this panel are concerned that little or no attempt is being made to replace key personnel because of budget pressures. The flat budget and the decrease of the permanent staff are the two biggest concerns of the panel.

While the panel commends the division for leveraging resources by using guest researchers to maximize efficiency and to create an interesting mix of permanent and flux employees, the panel 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 a long-term negative impact on the division and its institutional memory. The division chief has been extremely adept at using guest scientists, postdoctoral researchers, and other assignees to supplement the permanent staff. Unfortunately, this approach must be considered only an interim step toward establishing a larger, more permanent core team. The most obvious way to accomplish a change in technology focus is to bring in people with the requisite knowledge and skills to complement the existing staff.

Even though guest researchers are indispensable to division success and play key roles in the

TABLE 3.5 Sources of Funding for the Manufacturing Systems Integration Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	7.9	7.5	8.4	8.1
Competence	0.4	0.4	0.3	0.1
ATP	0.9	1.0	0.3	0.0
OA/NFG/CRADA	1.0	0.9	0.7	0.9
Total	10.2	9.8	9.7	9.1
Full-time permanent staff (total)[a]	41	35	32	30

NOTE: Sources of funding are as described in the note accompanying Table 3.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

division, they unfortunately are not treated as first-class citizens. For example, no mechanism exists for including guest researchers in the bonus program, and they cannot be trained for emerging technologies at NIST expense even though this education furthers NIST's needs. Since it is anticipated that such nonpermanent but often long-term employees will continue to make up a majority of the workforce, such issues need to be considered by NIST.

Staff is the division's most important resource; there is clear and evident pride on the part of the scientists, engineers, and administrative people working for NIST. Working for NIST with its high-caliber staff in the objective and open NIST environment contributed to positive staff morale. Division staff members interact with their counterparts in other divisions and enjoy the open exchange of ideas through technical seminars. Knowledge sharing is part of the culture of this division, and there seems to be ample opportunity for staff learning and education.

The panel believes that the division might further enhance staff morale through its recognition of technical accomplishments. Financial rewards might be difficult, but certainly public recognition might further enhance the already-positive morale. Clearly, the technical accomplishments of the group are significant, and being perceived as such by peers and customers would be received positively.

Computer resources seem to be appropriate. Both hardware and software appear adequate and are highly leveraged by division staff.

Division programs are matrix-managed, with a large number of projects and tasks in each program. Because the staff is thinly spread across these projects and tasks, it is highly important that programs be aimed at common and mutually supportive objectives and that the scientists and engineers know their roles in the master plan of the division. In addition, each person must be able to articulate his or her place and contribution to the major goals. These intradivisional interactions need attention. The scientific and support staff have strong faith in the management and will support the leadership. As stated, the division still has too many tasks for the size of its staff, and although the number of projects has been pruned since last year's assessment, there are still too many. The panel would be happier with a lower ratio of tasks to people to ensure quality and timeliness of results.

4

Chemical Science and Technology Laboratory

PANEL MEMBERS

James W. Serum, SciTek Ventures, *Chair*
Alan Campion, University of Texas, Austin, *Vice Chair*
Ulrich Bonne, Honeywell Laboratories
Douglas C. Cameron, Cargill, Inc.
Robert E. Ellefson, Inficon, Inc.
E. William Kaiser, Ford Motor Company
John W. Kozarich, ActivX Biosciences, Inc.
Max G. Lagally, University of Wisconsin-Madison
R. Kenneth Marcus, Clemson University
James D. Olson, The Dow Chemical Company
Athanassios Z. Panagiotopoulos, Princeton University
Frank K. Schweighardt, Air Products and Chemicals, Inc.
Gary S. Selwyn, Los Alamos National Laboratory
Michael L. Shuler, Cornell University
Christine S. Sloane, General Motors Corporation
Anne L. Testoni, KLA-Tencor Corporation
Peter Wilding, University of Pennsylvania Medical Center

Submitted for the panel by its Chair, James W. Serum, and its Vice Chair, Alan Campion, this assessment of the fiscal year 2002 activities of the Chemical Science and Technology Laboratory is based on site visits by individual panel members, a formal meeting of the panel on March 12-13, 2002, in Gaithersburg, Md., 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 FY2001,* NISTIR 6856, National Institute of Standards and Technology, Gaithersburg, Md., February 2002.

LABORATORY-LEVEL REVIEW

Technical Merit

The mission statement of the Chemical Science and Technology Laboratory (CSTL) is as follows: As the Nation's Reference Laboratory for chemical measurements, CSTL provides the chemical measurement infrastructure to enhance U.S. industry's productivity and competitiveness; assure equity in trade; and improve public health, safety, and environmental quality.

CSTL continues to carry out research of excellent technical merit overall. The panel wishes to draw attention here to several outstanding examples:

- "Ionic liquids" are a class of organic compounds that have been proposed as environmentally friendly solvents for some important industrial processes. This past year, CSTL initiated a program to obtain and disseminate fundamental physical and chemical properties data for some of these compounds in order to facilitate industrial adaptation of these new solvents. The laboratory has anticipated industry need for these data—to the extent that the compounds are not yet available commercially and must be synthesized in-house for study.
- The laboratory is also continuing work to control and characterize fluid flow in microfluidic devices. This work is noteworthy not only because of its world-class technical merit but also because of the strong industrial involvement in the program and its applicability across a broad spectrum of problems in chemistry, biology, and medicine.
- Fluorescence spectroscopy is an old "workhorse" technique used in biochemical assays. Despite its long history of use, few standards exist for measuring the intensity of the fluorescent signal, making quantitative assays using this technique unreliable at best. Because of increased use of fluorescent techniques in clinical applications, CSTL is developing standards for these measurements, which will have a significant impact on the quality of clinical measurements made using this technique.
- CSTL efforts to develop high-throughput characterization of particle properties is not only relevant to industries as diverse as paints and coatings manufacturers and semiconductor manufacturers but is noteworthy for its interlaboratory collaborations.

Several programs were noteworthy for the use and development of cutting-edge technologies. A new primary standard for pressure is under development; it determines pressure by measuring and calculating the dielectric constant of helium rather than by using the mechanical artifacts of existing pressure standards. CSTL work on characterizing degraded DNA samples is pushing forward the state of the art in mass spectroscopic techniques. In work aimed at characterizing "soft" surfaces such as biomaterials and polymers, the laboratory is developing new cluster-ion secondary ion mass spectrometry (SIMS) techniques.

The Chemical Science and Technology Laboratory is organized in five divisions: Biotechnology Division, Process Measurements Division, Surface and Microanalysis Science Division, Physical and Chemical Properties Division, and Analytical Chemistry Division (see Figure 4.1). These units are reviewed in turn under "Divisional Reviews" below in this chapter.

Program Relevance and Effectiveness

The panel found CSTL to be very proactive overall in identifying the customers of its work. In most cases, researchers have a good understanding of how their work meets the needs of those customers. In

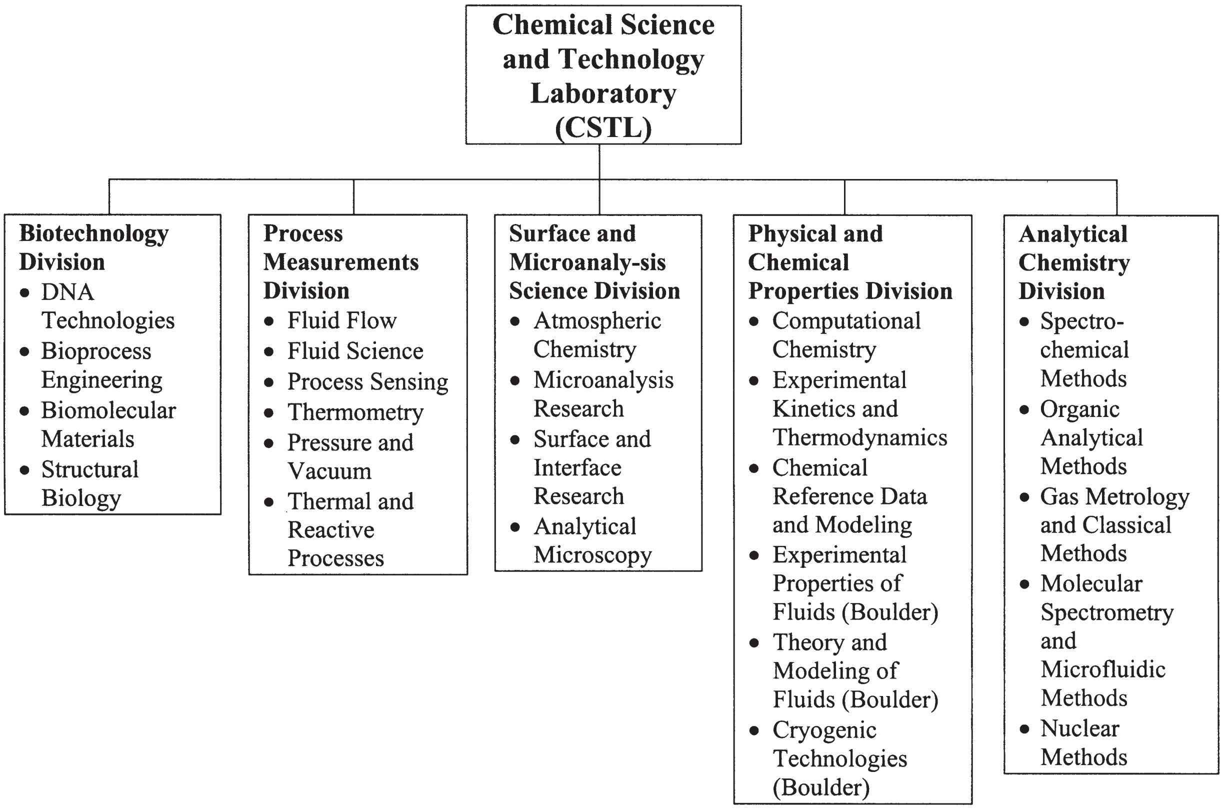

FIGURE 4.1 Organizational structure of the Chemical Science and Technology Laboratory. Listed under each division are the division's groups.

addition to their technical description, all projects presented to the panel had a concise statement of the anticipated industrial use. The panel was pleased to see an increased awareness of customer impact since its last assessment.

Particularly noteworthy for their relevance and effectiveness are the laboratory's efforts in Standard Reference Materials (SRMs), Standard Reference Databases (SRDs), and international standards activities. These services and activities rarely garner headlines but have a large leverage effect in industry and underpin many critical measurements in the chemical, pharmaceutical, medical, and other industries. For example, the laboratory recently completed a series of SRMs for in vitro diagnostic testing. These SRMs will allow U.S. manufacturers to qualify their products for sale in the European Union. The panel anticipates that the positive impact for U.S. manufacturers will be substantial. NIST-Traceable Reference Materials (NTRMs), discussed in the Analytical Chemistry Division assessment below, have tremendous leverage in the chemical products industry and are also of value to National Laboratories, environmental laboratories, academic institutions, and other industries. Web-based databases are growing in size and number and are improving in quality. The panel is pleased with CSTL efforts in Web-based dissemination and finds that the laboratory's Web-based dissemination continues to improve in utility and effectiveness. The laboratory has now hired a staff member dedicated to the effectiveness of Web usage and maintenance, which the panel applauds. However, funds are insufficient to maintain and update all of the laboratory's Web-based tools. The panel is concerned about the utilization of these databases if CSTL does not take advantage of the opportunity that the Web provides to continually update material. The laboratory needs to develop a strategy to determine how it will utilize its limited resources for Web-based dissemination.

Laboratory Resources

Funding sources for the Chemical Science and Technology Laboratory are shown in Table 4.1. As of January 2002, staffing for the laboratory included 270 full-time permanent positions, of which 232 were for technical professionals. There were also 92 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The panel observed too many priority projects with subcritical resources devoted to them. It may be that CSTL needs to reexamine its prioritization, either to find additional resources for top priorities that are undersupported or to terminate efforts that cannot be supported effectively. CSTL has also targeted certain areas for strategic program growth. The panel cautions against implementing strategies in these areas too quickly, before the appropriate expertise is in place to launch efforts most effectively. For example, the CSTL program in tissue engineering does not seem to have the complete skill set necessary to meet its goals.

TABLE 4.1 Sources of Funding for the Chemical Science and Technology Laboratory (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	37.9	37.7	36.9	37.7
Competence	2.4	2.4	1.9	2.7
ATP	3.0	3.3	3.2	2.4
Measurement Services (SRM production)	2.4	2.2	1.9	1.9
OA/NFG/CRADA	10.9	14.2	14.3	15.4
Other Reimbursable	3.4	3.4	5.8	5.1
Total	60.0	63.2	64.0	65.2
Full-time permanent staff (total)[a]	276	275	264	270

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.

Strategic program goals must be coordinated with a plan for resources, including human resources, in order to ensure that resources are fully leveraged and programs have a sufficient critical mass to be effective. The panel is concerned that CSTL lacks a human resource plan, which would enable better personnel development, succession planning, and acquisition of new skills through hiring or retraining.

The panel recommends that the laboratory utilize a fellowship program for rapid development of the technical expertise needed for growth areas. A program in which NIST researchers spend a period of several months to a year in industry can greatly facilitate bringing new skills into the laboratory. All fellowships awarded must include a clear plan for how the new skills of the awardee will be used once he or she returns to NIST. The program must also be clearly tied to advancement, reward, and recognition to give employees an incentive to participate.

Midlevel managers in CSTL, especially group leaders, are being called on to exercise an increasing number of skills. They generally maintain an active research program while tending to personnel management, leadership of staff, and marketing of programs to industrial customers. Little training seems to be provided to support them in this work. The panel urges a proactive approach to training managers and prospective managers in these areas in order to enable their success. The result should pay off for the laboratory in terms of better coordination of programs, better communications to all levels of staff, and higher overall staff morale.

Facilities for CSTL research have improved greatly in the past 5 years, and the completion of the Advanced Measurement Laboratory (AML) will have a major positive impact. Equipment on hand is generally state of the art, although in some cases the equipment needed to meet goals is not in place. The panel believes that CSTL should clarify its thinking on an in-house microelectromechanical systems (MEMs) production facility. The panel did not see a clear rationale for a decision to procure that capacity in-house versus obtaining it off campus. Because of the high cost of maintaining such a facility, the panel recommends that CSTL and NIST be certain that any make/buy decision on MEMs production take into account the long-term costs of such a facility. The panel is pleased to see that the Hollings Marine Laboratory in Charleston, South Carolina, in which CSTL is a partner with NOAA and state agencies, is being appropriately equipped from the outset.

Laboratory Responsiveness

Clear examples of strong responsiveness to last year's report[2] exist. For example, in response to panel comments, time and funds were reprioritized to increase efforts in international activities and collaborations in analytical chemistry. Some divisions greatly enhanced the usability of their Web-based information, also in response to panel recommendations.

Responses in some areas were not as strong. For example, the panel has pointed out the lack of critical mass in program areas such as atmospheric chemistry. While recognizing that it is difficult to make decisions to redirect resources, some situations have been allowed to linger despite repeated comments from the panel. Such situations are having an increasingly negative impact on the morale of involved staff members.

In general, the panel is satisfied with the CSTL's response to its 2001 report. It urges the laboratory to try harder to respond to the more difficult recommendations or to provide better explanations for why these recommendations were not acted upon.

[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.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- Chemical Science and Technology Laboratory programs continue to have high technical merit overall.
- Awareness of customer needs and customer impact is increasing at all levels of CSTL staff.
- The panel is pleased with improvements made to CSTL use of the World Wide Web. Hiring a staff member devoted to Web utilization and Web-based dissemination is a positive step. A strategy is needed for Web-based dissemination, as databases currently exist that are not kept up to date.
- CSTL needs a human resources plan that can be integrated with the CSTL strategic plan to account for the training, hiring, and succession planning needed to achieve laboratory goals and objectives.
- CSTL should utilize industrial fellowships to learn more about its customers and to quickly gain skills necessary to achieve objectives in new and emerging areas. Any plan to place a staff member in industry for an extended period must include a plan for how that person will utilize new skills upon returning to NIST. In order to attract staff participation, industrial fellowships must be tied to advancement, reward, and recognition.
- More proactive training of group leaders is required to help them achieve success in the multiple roles they are called on to fill in their positions.
- CSTL should reexamine the rationale for its decision on building a microelectromechanical systems fabrication capacity in-house. If the decision is made to go forward with an on-campus facility, a long-term plan is necessary to provide for the cost of maintaining and utilizing it.

DIVISIONAL REVIEWS

Biotechnology Division

Technical Merit

According to division documentation, the mission of the Biotechnology Division is to advance the commercialization of biotechnology by developing the scientific and engineering technical base, reliable measurements, standards, data, and models to enable U.S. industry to quickly and economically produce biochemical products with appropriate quality control. The Biotechnology Division has four groups: DNA Technologies, Bioprocess Engineering, Biomolecular Materials, and Structural Biology. The division is also evolving a Bioinformatics Group from the Structural Biology Group. The division's ongoing programs are appropriately aligned with its mission, and the scientific work is of high quality comparable with that at research-oriented universities and in leading industrial laboratories. The division's challenge is to select those projects that are most critical and that will have the greatest impact on this rapidly growing and changing field.

The DNA Technologies Group carries out research to enhance measurement technologies and to provide SRMs for application in areas related to the detection and characterization of DNA. The group maintains a strong focus on standards development, nucleic acid characterization, and measurement development for the diagnostic and forensic communities. The group's programs are quite wide ranging and are, in general, of outstanding quality.

The DNA Technologies Group is pioneering the development of SRMs for human identification and is developing a critical database on short tandem repeats (STRs). The development of these methodologies for human identification is being carried out in collaboration with and with the support of the National Institute of Justice. This research is state of the art and continues to push the technology into new, productive, and high-impact areas. The development of new high-speed matrix-assisted laser desorption ionization (MALDI) time-of-flight mass spectrometric techniques with automated sample preparation is addressing the need for high-throughput analysis of genetic samples. Projects focusing on identification methodologies for the Y chromosome and mitochondrial DNA continue to make impressive progress. The development of Y-STR megaplex assays will greatly increase the acceptance of these identification techniques within the forsenic community. Genotyping of single nucleotide polymorphisms in the Y chromosome and the mitochondrial genome, the development of the prototype Y chromosome standard (SRM 2395), and the enhanced version of the human mitochrondrial DNA SRM 2392 have all progressed well in the past year.

The DNA Technologies Group has also successfully integrated state-of-the-art instrumentation into its programs. One CRADA with a biotechnology company led to the development of rapid capillary electrophoresis (CE) methods for mutation detection. Other work has focused on developing procedures for single-strand conformation polymorphism detection by CE. Another major program has centered on developing methods for detecting and quantifying DNA damage and repair in cancer detection and treatment. Methods have been developed to characterize DNA damage on a molecular scale at levels approaching one base per million using gas chromatography/mass spectrometry (GC/MS) techniques. These methods have been useful in the study of the kinetics and specificity of DNA repair by specific enzymes. Additional studies are concentrated on apoptosis, or programmed cell death, as well as detection of cellular responses to radiation. This work has potentially high-impact value.

The DNA Technologies Group also houses the NIST/National Cancer Institute (NCI) Biomarker Validation Laboratory (BVL), part of NCI's Early Detection Research Network (EDRN). The BVL validates biomarkers of early cancer detection and cancer risk, supports the development and implementation of high-throughput biomarker analysis, and collaborates with Network Clinical and Epidemiology Centers (NCECs) in technology transfer. The panel was impressed with the accomplishments of the past year, including validation analysis of fluorescence in situ hybridization (FISH) for cancer risk analysis; technical improvements in polymerase chain reaction (PCR) DNA sequencing technology for analysis of mitochondrial DNA base mutations for lung cancer; and the development of capillary electrophoresis methods for analysis and quantification of telomerase. The work is cutting-edge and of high impact.

The Bioprocess Engineering Group develops measurement methods, databases, and generic technologies related to biomolecules and biomaterials in manufacturing. The group, which consists of 12 researchers, has activities in eight areas: (1) fluorescence intensity measurements, (2) biothermodynamics, (3) biotech grain testing, (4) quantitative PCR reference materials, (5) chorismate pathway enzymology, (6) biocatalytic hydroxylation/epoxidation, (7) bioelectrochemistry, and (8) DNA separations. The quality of the group's work is high, and its activities and accomplishments are clearly presented in a useful and well-designed Web site.

The Structural Biology Group participates in the Center for Advanced Research in Biotechnology (CARB), a joint NIST/University of Maryland (UMD) research center located on the Shady Grove campus of UMD 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. Current programs in x-ray crystallography, biomolecular nuclear magnetic resonance (NMR) spectroscopy, protein folding, computational chemistry and modeling, and mechanistic enzymology are outstanding. The NIST component of CARB has succeeded in attracting several first-rate young investigators who have nicely blended their NIST-focused programs into the academic culture that they share with their UMD colleagues. The result is a stimulating research environment that maintains the mission-oriented flavor critical to NIST programs. Notable programs include research on the biothermodynamics of protein/protein and protein/nucleic acid interactions, single-molecule measurements, studies on computational molecular evolution, and the development of cell membrane hybrid bilayers for a high-throughput screening assay for membrane receptors. In addition, ongoing work on the x-ray and NMR structures of proteins and nucleic acid is of high quality.

The newly evolved Bioinformatics Group has four major projects: the Protein Data Bank (PDB), the Biomolecular Crystallization Database (BMCD), the Bioinformatics Software Resource (BISR), and the HIV Protease Structural Database (HIVDB). The PDB is a major national and international resource and a very visible success for NIST. The goal of the BISR is to create a database of commercial and noncommercial bioinformatics software. The panel was gratified to learn that the group has developed educational and outreach materials for high schools and has hired high school students to work in the laboratory. Overall, this group is making exceptional contributions to bioinformatics. Hiring and retention are continuing challenges for the group owing to a high demand for such skills in the biotechnology and pharmaceutical industries. The group currently consists of approximately 10 people.

The Biomolecular Materials Group builds on its skills in surface science, optics, biophysics, and chemistry to support research in protein structure/function relationships, biopolymer transport processes, biosensors, molecular recognition, protein/lipid and protein/protein interactions, mechanism of protein adsorption, and tissue engineering. The panel was very impressed that the group was awarded two NIST Competence programs with funding through FY 2007. The first, Single Molecule Manipulation and Measurement (SM^3), is a collaboration between CSTL, EEEL, ITL, and PL. This program builds on the group's historical strengths. Research planned in single-molecule force metrology and single-nanopore-based analyte sensors is particularly noteworthy. The second, Metrology for Tissue Engineering: Test Patterns and Cell Function Indicators, involves collaboration with MSEL. The tissue engineering effort is newer to this group. This program focuses on the use of indicator cells to evaluate cellular response to exposure to a new biomaterial. While most of the group's efforts are understaffed in comparison with the potential of the research problems, the addition of more staff to the tissue engineering effort is particularly critical. At the time of the panel's visit, a search was under way for a postdoctoral associate. Filling this position with an appropriately trained individual will be important to ensure rapid progress. The group is well situated to make contributions to these exciting and rapidly evolving research areas with its strong intellectual leadership and first-rate science and technology.

Program Relevance and Effectiveness

The Biotechnology Division has selected a wide range of exciting emerging research areas that will be critical to the nation's future industrial competitiveness and safety. The division is well positioned to support efforts in genomics, proteomics and structural biology, tissue engineering, standards for genetically modified crops, and characterization and manipulation of single molecules such as DNA. As a whole, the division has selected a very appropriate set of research areas to which to apply its limited resources. The panel and the division both recognize that the range of potential issues in biotechnology is vast and that the potential number of customers for the division's work is in the thousands. Since all of these issues and many potential customers cannot be served by a group of the division's size, the prioritization of research problems is critical. The panel concurs with the priorities chosen by the division.

The division demonstrated its ability to respond to customer needs on an emergency basis in its response to the fall 2001 terrorist attacks. The DNA Technologies Group has developed new techniques to permit identification of persons from highly degraded DNA and is assisting agencies that are using these methods to help identify victims of the World Trade Center attacks.

The Biotechnology Division is by nature cross-disciplinary and has strong international connections. The two Competence awards to the division promote cross-division and cross-laboratory collaborations and communications. The interaction with CARB also promotes an externally oriented perspective. The Protein Data Bank is an international effort. The division is a coleader of the Consultative Committee for the Amount of Substance Biometrology Working Group. This activity involves about 30 countries. Division scientists played an important role in the recommendations of the International Union for Pure and Applied Chemistry (IUPAC) for differential scanning calorimetry measurements. Division staff members played leadership roles in the Second International Conference on Oxidative Stress and Aging, sponsored by the Oxidative Stress and Aging Association.

The division makes substantial use of the Web to disseminate information. It maintains four major databases: the Protein Data Bank (a research collaboratory for structural bioinformatics), the Biological Macromolecule Crystallization Database (SRD 21), the Short Tandem Repeat DNA Database, and the Thermodynamics of Enzyme-Catalyzed Reactions Database (SRD 74). These databases are important resources for scientists worldwide. Some units (e.g., the Bioprocess Engineering Group) have made significant improvements to their Web sites in the past year.

The panel notes that the research in the division aligns well with three strategic focus areas identified in the NIST strategic planning process: health care, nanotechnology, and knowledge management. The central focus of the division is closely related to health care. The SM^3 program has necessitated the division's development of expertise in nanotechnology. The division's bioinformatics programs are an important example of knowledge management.

The panel reviewed the division's responsiveness to prior reports. The primary challenge to the division's ability to maintain relevance and responsiveness to customers is that of maintaining and developing critical mass in emerging areas. This challenge requires the division to reassess research priorities constantly and to encourage staff development in new areas. The panel has seen clear evidence of strategic planning and of reprogramming, particularly in genomics and proteomics, nanotechnology, and tissue engineering. The panel also expressed concern last year about maintaining the proper balance between STRS monies and funding from other sources. While some increase is seen in the use of other funding, particularly with the DNA Technologies Group, the panel believes other groups could benefit from a higher proportion of outside funding. It is difficult to change this balance rapidly.

The DNA Technologies Group has maintained high external visibility and programmatic relevance, as evidenced by the high level of external funding 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 group is well positioned to respond to customer needs in genomics and proteomics. However, given the general manpower and resource constraints that it is facing and its deep commitment to several key external programs, the group may be spreading itself too thin and may not be able to mount the kind of program needed in proteomics. The leadership of the group and the division must carefully assess priorities and resource distribution to assure that key programs are adequately supported. The group should also develop a plan that prioritizes proteomics efforts consistent with ongoing commitments and the current expertise base.

The Bioprocess Engineering Group has made significant contributions in each of its eight areas but is spread too thin for a group of 12. The panel recommends its reducing the number of project areas and aligning better with the NIST Strategic Focus Areas of health care, nanotechnology, and knowledge management. One promising area that would draw on the group's strengths is the characterization of complex, heterogeneous proteins such as the glycosylated protein drugs being developed by the pharmaceutical industry. Currently, the Bioprocess Engineering Group does not rely on outside funding for any projects. Increasing the amount of outside funding to around 20 percent could allow the division to increase the number of researchers on each project and would demonstrate external buy-in to projects. The group's biotech grain testing and quantitative PCR reference materials projects are areas of growing importance in the food and agriculture industries; such testing and standards are important for regulatory compliance, human health and safety, global trade, and identity preservation of crops. This effort is highly responsive to NIST customer needs and has resulted in CRADAs with seed companies. The number of people working on this project in the Bioprocess Engineering Group has doubled, from one to two, since last year, but is still understaffed relative to its full potential. The Bioprocessing Engineering Group should continue to strengthen its interactions with the DNA Technologies Group to further leverage its efforts.

The Bioprocess Engineering Group continues to deliver high-quality thermodynamics data, as evidenced by the recent publication of thermodynamic quantities for the ionization reactions of biological buffers. The group has also released thermodynamics software. However, the software requires Mathematica, a program that is widely available in academia and in engineering groups in industry but not commonly used by biologists. For the use of its biothermodynamics data, the group should consider developing software that is built on more commonly used software such as Excel or that can be used directly via the Internet.

The relationship to CARB is a critical issue for the Structural Biology Group. The University of Maryland began the CARB collaboration more than 10 years ago. In the panel's judgment, the NIST and university cultures have been integrated successfully. The current group of NIST investigators at CARB has straddled both cultures effectively. Young NIST investigators are competitive with the best young academic faculty nationwide. However, with regard to manpower and resources, the NIST component of CARB appears to be at a crossroads. NIST manpower levels at CARB are at or near their lowest point, and the division is clearly concerned about NIST's commitment to rebuilding its presence at CARB in light of flat budgets and decreasing permanent positions. This situation is exacerbated by the fact that another expansion of CARB has been planned, and it is not clear to the Structural Biology Group if NIST will commit the kind of resources needed to maintain a robust presence relative to its UMD peers. CARB has been an important and successful collaboration for NIST, but a clear strategic vision needs to be articulated for the NIST role in the future of this institution. The ongoing search for a new CARB Director also contributes to staff anxieties over the future.

Despite these uncertainties, the Structural Biology Group is expanding its interactions with industry in the vibrant biotechnology sector found in the Washington, D.C., area. A new CRADA with MedImmune was established to undertake a thermodynamic characterization of monoclonal IgM using calorimetric methods. Another new CRADA with Genetics Institute, Inc. explores biophysical and crystallographic attributes of thioredoxin fusion peptides and proteins.

The Bioinformatics Group faces several challenges in maintaining program relevance and effectiveness. The PDB project, an important and high-impact resource for the molecular biology community, will be challenged to keep up with the large number of new protein structures that will be generated by large-scale proteomics projects. The BISR project has the worthy goal of creating a database of commercial and noncommercial bioinformatics software. The panel suggests that one way to strengthen and grow this effort is to convince the key bioinformatics journals to require that software mentioned in publications be archived in such a database. As part of the HIVDB project, the Bioinformatics Group is developing tools for structural-based queries for drug interactions. The panel was impressed with the initial progress of this effort and recommends that feedback from industrial medicinal chemists be incorporated into the query tools. The panel also recommends that the drug interaction database be extended beyond proteases to other proteins such as protein kinases. Overall, this group is responsive to a wide range of users and has a strong customer-service orientation.

The Biomolecular Materials Group is very forward looking, and its targeted technologies are just emerging in the industrial sector; the two recently funded NIST Competence programs mentioned above confirm the potential relevance of its efforts. Because of the emerging nature of the technology it is working on, this group has fewer obvious links to industrial firms. However, its projects have explicit relevance to tissue engineering firms and to regulatory agencies such as the Food and Drug Administration (FDA). The SM^3 project is addressing issues that will be needed in biomicroelectromechanical systems (bioMEMs) projects. Efforts to validate new methods for characterizing nanopores with "molecular rulers" and for DNA sequencing are also important. The research on high-density biological arrays has clear relevance to high-throughput proteomics and to biohazards detection, both of which are critical research areas that would benefit greatly from improved detection techniques. The relevance of this group's work to supporting critical emerging technologies is high. However, the panel would like a better understanding of how the group will actively link its contributions to customers.

Division Resources

Funding sources for the Biotechnology Division are shown in Table 4.2. As of January 2002, staffing for the division included 37 full-time permanent positions, of which 32 were for technical professionals. There were also 24 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The availability of adequate human resources remains the critical resource issue for the division. Funding and personnel numbers estimated for 2002 are up by about 8.5 percent compared with those for

TABLE 4.2 Sources of Funding for the Biotechnology Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	6.5	6.5	6.6	6.9
Competence	0.8	0.8	0.4	1.0
ATP	1.7	1.9	1.3	0.7
Measurement Services (SRM production)	0.1	0.0	0.3	0.2
OA/NFG/CRADA	1.7	2.2	1.9	2.8
Other Reimbursable	0.1	0.3	0.2	0.2
Total	10.9	11.6	10.7	11.8
Full-time permanent staff (total)[a]	37	35	32	37

NOTE: Sources of funding are as described in the note accompanying Table 4.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

2001. The panel is pleased to note this slight growth. The rapidly changing nature of research opportunities in biotechnology will always challenge the division to assemble the critical mass of human resources needed to attack these emerging opportunities. As a whole, the division has managed its resources well. However, expertise in plants, animal cell culture, and tissue engineering is rather minimal for supporting the aspirations of the division and the needs of its customers. The panel appreciates the difficulty of expanding core personnel in the current fiscal environment, but human resources are the primary limitation for the division (also, see the discussion on manpower levels at CARB in the preceding subsection, "Program Relevance and Effectiveness").

The division lost two staff members in bioinformatics in the past year. NIST can expect significant competition for personnel in bioinformatics. Many organizations in the Washington, D.C., area can pay people with these skills much more than government agencies can. The growth of the local biotech industry and the expansion of the Howard Hughes Medical Foundation will mean a highly competitive local job market in biotechnology. As the economy recovers, this competition will only intensify.

The challenge of employing human resources optimally is affected not just by the supply of funds but also by the type of fiscal support currently available in the laboratory. The internal STRS funds do not currently cover the salaries of all of the division staff, which has led to a significant dependence on support from other agencies. Different programs within the Biotechnology Division appear to have different attitudes toward the use of noncore funding and its application to staffing. In some programs, staff aggressively pursue OA funding in order to hire new personnel and expand into new areas. In others, permanent positions are not created unless they can be supported by NIST core money. The former approach embraces risk and increases the potential impact of a group's work, while the latter allows program managers to be assured that mission-critical activities are sustained and NIST's customer base will be served. The panel recognizes that both approaches have value, but suggests that modest dependence on external funds be encouraged.

The panel also noted a need for increased computer support and additional disk storage space for the Bioinformatics Group.

Process Measurements Division

Technical Merit

The Process Measurements Division's mission is to pursue basic research efforts in measurement science; enhance the state of the art in measurement standards and services; provide recommended measurement techniques; standardize recommended practices in sensing technology, instrumentation, and mathematical models required for analysis, control, and optimization of industrial processes; and provide a central, national source for calibration of measurement equipment. The Process Measurements Division has six groups: Fluid Flow, Fluid Science, Process Sensing, Thermometry, Pressure and Vacuum, and Thermal and Reactive Processes.

A core responsibility of the Process Measurements 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. The division also interacts with its counterparts in other countries and represents the United States at international measurement science conferences. The division's research currently supports 6 of the 12 major CSTL programs with a broad range of research in new and traditional fields, development of world-class measurement methods, standards, calibration services, and measurement of important physical properties for industry. The division's efforts are divided among the development of calibrations and reference materials, the development of new measurement methods, and database activity. The division staff balances its activities in order to perform its dual roles of addressing the calibration and reference material needs of customers and advancing the state of the art in measurement science in the fields applicable to the division's mission.

The panel is impressed by the concentration of measurement knowledge and expertise in this division and by the quality of its work. The technical merit of its work remains high. The panel noted major progress in the development of new cutting-edge measurement technologies and improvements in measurement and calibration uncertainties in flow, pressure, temperature, and humidity. Ongoing efforts in the development of new sensors, measurement methods, and process models show good progress. Some highlights of the division's work in the past year are presented below.

The division has improved flow measurements in the 1 to 1,600 L/min range with a newly completed, automated pressure-volume-temperature flow accumulator. This improvement reduces the uncertainty of flow calibration results by a factor of 4 relative to the old mercury-sealed calibrator pistons and the still-older bell-prover method, which the division has now phased out. The division's leadership in the area of flow measurement is evidenced by its staff members chairing the BIPM/CIPM (Bureau Internationale des Poids et Mésures/Comité International des Poids et Mésures) Working Group for Fluid Flow and the Sistema Interamericano Metrología (SIM) Metrology Working Group for Fluid Flow.

In FY 2001, the division participated in four Consultative Committee for Mass and Related Quantities (CCM) Key Comparisons (KCs) and piloted three of them, two to completion of Draft B reports. These two completed comparisons were notable for being the first successful international comparisons in this pressure range (which was due to the division's innovative transfer standard design) and for being the only CCM pressure comparisons to be completed on time. The division is developing a pressure standard based on the dielectric constant of helium to provide an alternative to the conventional deadweight methods for intercomparison standards. The division has come to within a factor of 10 of the accepted pressure-sensing uncertainty standard. Before this new standard is available, NIST may need to replace aging piston gauges for the old standard in order to maintain competence for industrial calibrations. In another effort related to pressure gauges, division scientists developed a portable transfer standard using a vibratory/resonant MEMS sensor that achieved impressive performance in terms of sensitivity and stability, as demonstrated with data taken in a NIST-directed international comparison of pressure gauges.

The division has been the pilot lab for the CIPM Key Comparison 3 (K3) covering temperatures from 84 K to 933 K (−189 °C to 660 °C). As the pilot lab, the division has authored a comprehensive report on K3, which was approved by the Consultative Committee on Temperature (CCT) in 2001. This is a major accomplishment in improving the ITS-90 standard in this temperature range and helps establish the equivalence of the measurements performed by various national measurement institutes (NMIs), a resource that is important to industry in international trade. The 8th International Decadal Conference, Temperature: Its Measurement and Control in Science and Industry, is being organized under CSTL's leadership.

The division completed constant-volume gas thermometry measurements up to 700 °C, demonstrating that the NIST spherical acoustical resonator produces the most accurate thermodynamic gas temperature measurements as a realization of the ITS-90 temperature scale. Work is in progress to improve the accuracy at higher temperatures by comparing acoustic and microwave resonances. The Competence project on Johnson Noise Thermometry, a further effort to develop new, practical temperature standards, has progressed beyond experimental design to the first prototype stage.

The division has collaborated with an ultradry gas manufacturer to demonstrate excellent agreement between atmospheric pressure ionization mass spectrometry and the division's cavity ring-down spectrometer (CRDS), measuring less than 10 ppb water vapor as produced by the division's Low Dew Point generator. A commercial version of CRDS for water vapor measurement at low parts-per-billion levels, a metric required by U.S. industry, is being evaluated by the group in collaboration with the manufacturer.

The division is also developing Evanescent Wave Cavity Ring-down Spectrometry as a diagnostic technique for remote sensing of chemicals. Tests with a broad-spectral-range light source have allowed measurement of water and trichloroethylene. The importance of this technology is indicated by the division's collaborations in this area with industry, national laboratories, and academia.

A new NIST Competence project on molecular electronics focuses on developing metrology to measure electrical properties of newly conceived molecular circuitry and appropriately aims at establishing metrologies for this new area of study. Another NIST competence project is dedicated to the rapidly expanding field of microfluidics needed in "lab-on-a-chip" applications and is presently measuring flow profiles before addressing sensing approaches. This resonates with the trend of chem-bio, biomedical, and analytical chemistry technologies. The division should lend its standard-setting and fundamental measurement science abilities to this rapidly growing field.

The division has developed three tools pertinent to plasma etch monitoring: radio frequency (RF) waveform analysis; planar, laser-induced fluorescence (PLIF); and neutral mass spectrometry. Analysis of RF as an indicator of plasma state has matured to a level at which the panel encourages testing on plasma etch tools used in semiconductor manufacturing. The division has demonstrated expertise in PLIF, which can provide a spatial map of both ground-state CF and CF_2 radicals in a plasma. The division should maintain plasma measurements of the neutral species, using mass spectrometry as a complementary measurement tool for plasma processes.

The division has achieved a detection level in the <1 ppm range using chemical microsensors utilizing MEMs microhotplate technology. This is sufficient sensitivity for detecting many chemical agents without preconcentration, as sought by the Defense Threat Reduction Agency. The division has successfully leveraged its microhotplate as a tool to explore catalytic, doped-metal-oxide, matrix, and thermal cycling approaches to trace gas detection. It has also established strong ties with customers, as evidenced by OA contracts and CRADAs. The panel cannot assess whether the metal-oxide/catalytic hotplate sensor is going to be sensitive and stable enough for the detection of all chemical agents but is impressed by the initiative taken in the division to work on this topic. To make gas sensors viable, the panel believes that a demonstration of stability and sensitivity should be early goals of the effort.

Program Relevance and Effectiveness

The panel is especially pleased with the effort made this year by the Thermal and Reactive Processes Group to contact semiconductor and tool manufacturers to identify metal and dielectric deposition process areas in need of modeling research. Contacts with semiconductor manufacturers identified atomic-layer deposition, plasma-enhanced chemical vapor deposition (CVD), and thermal CVD modeling and measurements for advanced integrated circuit (IC) interconnects as areas in which the division has expertise and equipment to address fundamental issues. The result of this outreach is a redirection of research within this group to metal-organic thermal CVD. Research will investigate the mechanism involved in CVD of metallic thin films. The panel looks forward to further feedback from industry participants on the progress of this work.

The division is continuing its dialog with manufacturers of semiconductor gas mass flow controllers. These companies use the thermophysical property data on reactive process gases to enable more accurate flow-rate calibration. As new data are obtained on these reactive gases, the preliminary results are posted on the Web with conservative uncertainties until final values are published. This makes rare data immediately available to the user community.

Making at least some of the division's databases freely available on the Internet boosts NIST's image in and appreciation from the technical community. It could also spur innovation and trade. The panel recommends continuing this effort. The panel commends the CSTL for providing unfettered access to the gas and liquid property data needed by the semiconductor industry. These databases might be usefully extended to include fluid property data needs for other sectors. Such a proactive approach will add to NIST's relevance to industry and further its contact and connections with U.S. industry. The panel also commends the division for maintaining a Web page with division results and accomplishments.

The division provides primary calibration of gauges and sensors used for temperature, humidity, pressure, and flow measurements over a wide range of operating parameters. The principal customers of this service are secondary calibration laboratories and industrial users who want fast, low-cost calibrations. The appropriate focus for the division's calibrations remains high accuracy, including in many cases information feedback on the design or condition of the gauge. The panel encourages continued efforts to automate these primary calibration services and consideration of the viability of lower-cost calibrations, where practical, to help free staff time for the evaluation and analysis rather than using it for data taking.

The division's work in the measurement of the basic thermophysical properties of gases generates and updates fundamental properties, such as speed of sound, heat capacity, density (equation of state), and viscosity, for a variety of gases needed by the semiconductor industry. Such data enable the prediction of calibration factors for mass flow controllers and for improvement of modeling used for CVD. These data fill an important need in the semiconductor and high-technology industries. Physical properties of hazardous gases heretofore unavailable, with uncertainty ranges of 0.01 to 0.5 percent, are being systematically measured, and preliminary data are being made freely available on the Internet and eventually included in NIST's physical property data publication series.

The panel encourages the division to benchmark activities as a way to measure performance and progress in pertinent areas. The panel would like to see indicators such as numbers of journal publications, citations of previous work, patents, CRADAs, Web site hits, and other measures of information creation, use, and transfer. Numbers do not tell the whole story of the effectiveness of NIST research, but comparisons of trends over the years can reveal migration of modes of information transfer and can aid researchers and management in evaluating their effectiveness.

Division Resources

Funding sources for the Process Measurements Division are shown in Table 4.3. As of January 2002, staffing for the division included 59 full-time permanent positions, of which 54 were for technical professionals. There were also 15 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The panel commends the division for its retention rate for postdoctoral researchers over the past 5 years. Retention of postdoctoral fellows provides one good source of qualified researchers to fill permanent CSTL staff positions. The panel would like to encourage the division to perform more benchmarking of its personnel efforts—for example, examining turnover at CSTL compared with that at other government laboratories.

The current economic downturn might provide a special opportunity for NIST to develop further industrial connections. Because many companies that normally operate within the field of use targeted by NIST have surplus employees and yet may not want to lose those well-trained employees perma-

TABLE 4.3 Sources of Funding for the Process Measurements Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	7.9	8.7	8.7	8.6
Competence	0.8	0.9	1.0	1.1
ATP	0.4	0.5	0.7	0.3
OA/NFG/CRADA	0.8	1.0	1.6	2.7
Other Reimbursable	1.2	1.1	1.1	0.8
Total	11.1	12.3	13.1	13.5
Full-time permanent staff (total)[a]	59	57	58	59

NOTE: Sources of funding are as described in the note accompanying Table 4.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

nently, the division might utilize an industrial sabbatical program, following the example of its present academic sabbatical program. In such a program, companies might detail employees to NIST while paying a portion of their salary. NIST would pay the balance of the salary and would gain by the insight and viewpoint provided by these industrial partners and through use of their expertise for NIST projects.

Surface and Microanalysis Science Division

Technical Merit

According to division documentation, the mission of the Surface and Microanalysis Science Division is to serve as the nation's reference laboratory for chemical metrology research, standards, and data to characterize the spatial and temporal distribution of chemical species and to improve the accuracy, precision, sensitivity, selectivity, and applicability of surface, microanalysis, and advanced isotope measurement techniques. The current mission statement does clearly and concisely define the division's current role and responsibilities within the CSTL and NIST.

The Surface and Microanalysis Science Division is organized in four technical groups: Atmospheric Chemistry, Microanalysis Research, Surface and Interface Research, and Analytical Microscopy. In addition to the personnel in these groups, the division staff includes two active and one emeritus NIST fellows. The fellows pursue very active research programs and provide mentoring and technical guidance to younger staff across division organizational boundaries. The division is fortunate to have its programs supported by these fellows, productive scientists who are internationally recognized as leaders in their fields.

Several changes were made to division organization in 2001. First, leadership of the Analytical Microscopy Group changed; the former group leader returned to work as a researcher, and another staff member assumed the leadership role. The panel compliments the division on enabling both individuals to fulfill career aspirations and allowing a smooth transfer of responsibility. Second, the Surface and

Interface Research Group, previously called the Surface Dynamical Processes Group, underwent a name change in order to reflect more accurately its current and planned activities.

The organization of the Surface and Microanalysis Science Division has generally enabled the division to respond effectively to the need for programmatic evolution while maintaining logical groupings of expertise by analytical method or class. Technical activities are organized at the CSTL and NIST program level, allowing many opportunities for collaboration across CSTL and NIST. Currently, division projects are aligned in support of CSTL's 12 programs and play a central role in four: Semiconductor Metrology, Nanotechnology, Chemical Characterization of Materials, and Environmental Measurements. In 2002, the division will be deeply involved in CSTL's newly defined programs in Biomaterials, Environmental Technology and Systems, Industrial and Analytical Instruments and Services, Microelectronics, and Emerging Technologies.

The technical programs in the Surface and Microanalysis Science Division are of very high quality. Staff continue to receive recognition for their work within NIST and from the larger scientific community and are much sought after as speakers at major international technical symposia, conferences, and workshops. The following section of the report discusses program highlights and issues relating to the projects under way in each of the division's four groups.

The Surface and Interface Research Group, formerly the Surface Dynamical Processes Group, conducts theoretical and experimental research into chemical processes at surfaces and interfaces. As with its name, the focus of this group has and will continue to evolve and change. In the past, the group focused almost exclusively on the development and application of molecular spectroscopy to surface reactions; now it is beginning to broaden its work to include the development and use of other surface-sensitive and high-spatial-resolution probes such as near-field scanning optical microscopy (NSOM), atomic force microscopy (AFM) of soft surfaces, and conductance-based scanned probes. The evolving emphasis in this group on the development of novel tools is especially commendable. The group maintains its position as an international leader in sum frequency generation optical spectroscopy (SFG-OS) of surfaces and buried interfaces. The leader of the SFG-OS project received the Department of Commerce Bronze Medal in 2002 in recognition of his seminal efforts in this area.

In FY 2001, the group ended research into reactions of radicals at surfaces. The group performed fundamental measurements of the interactions of ground-state (^{3}P) and electronically excited (^{1}D) oxygen radicals with fused silica. This is a system of strong interest to the semiconductor and biomaterials industries, as oxygen radicals are the key reactive species in oxygen plasma reactors used for resist ashing and surface cleaning in semiconductors processing, and in polymer surface modification for biocompatibility in biomaterials. Fused silica is used for plasma containment, and it is important that the reaction models be known in order to help plasma scientists predict species lifetime and reactivity. It is unfortunate that this important research has been discontinued. The panel suggests that the division establish contact with plasma reactor companies to determine whether the research can be continued with outside resources.

The Surface and Interface Research Group is participating in two new CSTL FY 2001 competence programs: (1) Molecular Electronics and (2) Polymeric Thin Films: A Test Bed for Combinatorial Methods. A primary component of the Molecular Electronics program focuses on new, two-photon and conductance-based scanned probes. The secondary component focuses on ultrafast SFG-OS and theoretical studies of electron dynamics. In the Polymeric Thin Films program, the group will contribute to the development of novel instrumentation for hyperspectral imaging and rapid sample analysis, including nanoscale optical probes for analysis at various wavelengths (ultraviolet [UV], infrared [IR], and microwave). The group has assembled and tested a scanning confocal microscope. The application of these tools to polymeric films, and particularly to rapid sample screening, is noteworthy.

The Surface and Interface Research Group continues its development of nonlinear optical probes and their application to surfaces and buried interfaces, which is of note because these techniques can serve as in situ probes capable of real-time monitoring of processes at the molecular scale. Two National Research Council postdoctoral fellows have worked to take vibrationally resonant SFG-OS past proof-of-principle and into important practical application by studying the formation kinetics of self-assembled monolayers. This method is being applied to study the chemistry of copper electrodeposition in situ.

Members of the Surface and Interface Research Group were recognized by the 2001 CSTL Technical Achievement Award for their paper describing an exciting advancement in ultrahigh-resolution analysis of materials.[3] It is applicable to many industrial-relevant systems, including polymer film and semiconductor surfaces.

The Microanalysis Research Group performs research at and beyond the state of the art in techniques for electron and x-ray beam microanalysis applied to understanding the chemical, morphological, and crystallographic properties of materials. The group's goal is to improve the analytical resolution, sensitivity, accuracy, and precision of measurements made with scanning electron microscopy, electron microprobe analysis, analytical electron microscopy, scanning Auger electron spectroscopy, x-ray fluorescence, and x-ray photoelectron spectroscopy. Members of this group are some of the most influential scientists in their fields; their work is of outstanding quality.

The Microanalysis Research Group continues to pioneer new spectrometers for x-ray microanalysis. Researchers are using x-ray microcalorimeter detectors developed by EEEL in Boulder, Colorado, to study the fundamentals of low-energy x-ray line generation (e.g., L, M, and N lines of medium to high atomic number materials). Data on the absolute energy position and relative line intensities are scarce but are essential to accurate qualitative and quantitative microanalysis. This group's researchers are uniquely and appropriately situated to advance this work. It will have impact on every industrial and academic group that uses energy dispersive and wavelength dispersive x-ray spectrometry—which takes in nearly every high-tech industry and university in the United States. Many workers in the semiconductor industry are anxiously awaiting commercialization of these microcalorimeter detectors and will shortly thereafter be seeking accurate low-energy x-ray line information. The Microanalysis Research Group is also furthering the commercialization of a new, high-throughput x-ray detector, the low-energy silicon drift detector. The panel believes that this work epitomizes what NIST should be doing—both developing new instruments to enhance metrology and performing measurements for standards.

Researchers in the Microanalysis Research Group are exploring the use of fractal analysis of particle shapes for automatic classification. The work in this area is highly interesting and important to many industries (for example, automotive and semiconductor) and to government agencies (such as the Environmental Protection Agency [EPA] and DOD) that must characterize or identify particles and their sources. The group is approaching this research with sound fundamental principles. The panel recommends that the activity be focused to address first an understanding of the critical parameters of more standard particles, such as those available commercially or through NIST. Ultimately, the goal should be to provide a software tool kit for individuals to use in particle identification. The panel recommends discussions with industry researchers responsible for generating particle-classification algorithms; this will help the group avoid repeating industry's efforts. The panel encourages the division to continue the

[3]Michaels et al., "Scanning Near-field Infrared Microscopy and Spectroscopy with a Broadband Laser Source," *J. Appl. Physics* 88(8):4832-4839, 2000.

development of such software tools on PC-compatible platforms for easy dissemination to potential customers.

The panel recognizes the quality and relevance of the work that this group is performing in understanding the fundamental science behind measurements of films using cross-sectional transmission electron microscopy (TEM). High-resolution TEM is often used to measure gate dielectric thickness during process development in the semiconductor industry. As films approach monolayers of thickness, accurate understanding of measurement errors and proper measurement methods are essential. This group's careful research has resulted in new models for building virtual gate dielectric stacks that can then be compared with experimental data for error analysis. The panel encourages the continuation and completion of this work, as it will help scientists at industrial laboratories provide more accurate measurements to semiconductor process development engineers, resulting in higher device yields and performance.

The panel encourages the Microanalysis Research Group to accelerate its focus on measurements of the surface and bulk of silicon-germanium (SiGe) films and substrates, especially with high spatial resolution. The panel recognizes the expertise that this group has in TEM, x-ray spectroscopy, and grazing incidence x-ray photoemission spectroscopy (GIXPS) that is being explored for application to this material system. High-performance microprocessor manufacturers such as Intel, IBM, and Advanced Micro Devices (AMD) are increasingly adopting SiGe substrates and films. Lack of adequate measurement methods is preventing wider adoption of these materials; wider adoption by domestic semiconductor manufacturers would give them a competitive edge in this important market. The panel also encourages the division to continue to expand efforts in high lateral resolution chemical and elemental mapping and characterization of surfaces and interfaces, including the development of new instrumentation and analytical methods. The panel encourages collaboration with other divisions outside of CSTL on these efforts.

The Atmospheric Chemistry Group continues to focus on carbon isotope metrology and on elemental/organic splits in the carbon content of airborne particulate samples. The most confounding aspect of air quality associated with particulate matter continues to be discrimination of the myriad of emission sources responsible for airborne particulate carbonaceous material. The Atmospheric Chemistry Group has appropriately identified two key needs that clearly fall within the NIST mission: SRMs of quantified particulate mixtures from known emission sources, and chemical methods (both physical measurements and data analysis) to profile and distinguish different types of emission sources from atmospheric samples. During the past year, the group has focused on three categories of activity consistent with the high-relevance elements identified in its mission:

1. *Providing reference materials to enhance the accuracy and precision of chemical measurements used for compliance with asbestos and air quality regulations.* The group's careful, systematic, and arduous asbestos research is an example of valuable and unique national service consistent with the core NIST mission. The panel recognizes the high quality of expertise applied to produce SRMs for critical certifications of asbestos measurements. In addition, the group released one new standard reference material—SRM 2784, Urban Dust—and four reference materials. However, in the broader mission beyond asbestos measurements, personnel limits prevent the group from moving to research with higher payoffs to address the critical need for reference materials representing mixtures of known and quantified particulate emission sources.

2. *Providing an analysis of the sensitivity of artifacts in the thermal-optical measurement of elemental/organic carbon ratios to chemical speciation and physical properties of an airborne sample*

and to temperature-ramp protocols used in the measurement process. This information could provide insights to highlight significant reliability concerns with this commonly used technique. It also might raise awareness of the consequent large uncertainties in emission-source apportionments that are based on its use. The rate of progress on this effort is compromised, however, by personnel limitations.

3. Applying analytical methods to assist specific clients where reliable and conveniently available technical competence is required. Examples include developing a reference protocol to measure gas mask leakage, and application of radiochemical measurements to carbon-date particulate samples from the EPA air quality field studies. These client-oriented projects are executed with competence.

The panel notes that the Atmospheric Chemistry Group has not aggressively pursued novel techniques for isotopic profiling of emission sources, a goal highlighted last year, because of personnel limitations.

The Analytical Microscopy Group conducts research on the chemical and structural properties of matter using ion- and photon-based microscopies. This includes understanding fundamental aspects of the excitation process, quantitation methods, standards development, and commercial instrumentation improvements. This group continues to be a premier source of research and applications for methods such as secondary ion mass spectrometry, laser Raman microprobe, and Fourier transform infrared microprobe. The group's work on the development of new SRMs for dopant profiling is essential for the semiconductor industry, and NIST researchers are viewed as the international leaders in this field. The panel encourages this work and looks forward to the release next year of the SRM 2133, phosphorus implant in silicon. The panel repeats its suggestion to develop other dopant profile standards of value to industry, such as boron, arsenic, and phosphorus in common metal silicides. The panel was impressed by the SIMS instrumentation that is undergoing installation in this group's laboratories and looks forward to seeing results from these instruments in next year's review. In other work, the group is taking a leading role in the investigations of how to perform very shallow depth profiling using time-of-flight SIMS and is developing cluster-ion SIMS techniques that will allow the composition of "soft" surfaces such as biomaterials and polymers to be characterized. The panel looks forward to seeing this work extended to practical materials in the future.

Homeland security has long been a focus of the research of the Analytical Microscopy Group. In past reviews, the panel has commended the high-quality work that this group has done in developing methods for analyzing particles in support of international nuclear safeguarding. The panel recognizes this year's work to apply autoradiography in order to increase and improve uranium particle sampling throughput by pre-selection. More recent work on developing methods for calibrating gas masks has been performed in collaboration with researchers in the Analytical Chemistry Division and in the Fire Research Division of the Building and Fire Research Laboratory. This interesting activity will continue in FY 2002 and should result in new methods for testing the efficacy of gas masks in the field using particle aerosols. Finally, the division has been assisting in the development of trace explosives detection portals (TDEP) as a method of screening airline passengers for explosives and drugs. The group's unique knowledge of high-accuracy and high-throughput methods for analyzing particle composition makes it appropriately positioned to drive new methods and standards for accurate screening for security threats. The group's work on the application of cluster-ion SIMS to studying known explosives will provide TDEP manufacturers with new ways of distinguishing harmful materials from the large background of benign organics.

In collaboration with the Process Measurements and Analytical Chemistry Divisions, the Analytical Microscopy Group released a new series of standards for Raman spectroscopy. This technique, widely used for the characterization of materials, has lacked a comprehensive set of standards. This work by NIST will enable researchers and instrument manufacturers to have more accurate quantitative information for compositional analysis.

Finally, the panel would like to recognize the extraordinarily high technical quality of the work of the division's two active NIST fellows. One is the internationally recognized expert in the generation and emission of electrons from solid surfaces under x-ray and electron-beam irradiation. This was tangibly recognized by the outside scientific community in FY 2001 with the American Vacuum Society's Albert Nerken Award. This fellow's work is essential to the accurate interpretation and quantitation of x-ray photoelectron and Auger electron spectroscopies (XPS and AES, respectively). Research projects under his direction in FY 2001 have produced key databases or updates: SRD 20 on X-Ray Photoelectron Spectroscopy released version 3.1 in April 2001, and SRD 82 on Electron Effective Attenuation Lengths released version 1.0 in September 2001. He is also active in encouraging young researchers inside and outside of NIST to continue and expand the work in this field. The second fellow is one of the leading researchers in electron microprobe analysis, pioneering the application of new x-ray detector technology on traditional platforms such as high-vacuum, high accelerating voltage SEMs as well as new instrumentation such as variable pressure and low accelerating voltage systems. He has been the driving force behind the implementation of microcalorimeter x-ray detectors on SEMs for small particle analysis; this work is helping to meet an essential need of the semiconductor and other industries dependent upon understanding the composition of extremely small features.

Program Relevance and Effectiveness

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, and nanoscale analysis of compounds of pharmaceutical interest using near-field scanning optical microscopy. The panel recommends that the division perform periodic, perhaps annual, formal comparison of its activities with those occurring in other CSTL divisions, other NIST laboratories, and appropriate domestic universities to ensure that the work is complementary, not overlapping.

Researchers visited or met with many different corporations in FY 2001 to consult on measurement methods, discuss potential collaborations, and gain insight into new work areas. Division researchers interacted with various industries, including the following: chemical (Dow, DuPont, Visteon, PPG); consumer products (Proctor & Gamble); aerospace (General Electric); semiconductor (AMD, Agere, Cirent, KLA-Tencor, SEMATECH); and analytical instrumentation (Noran, Gatan, Photon Imaging, X-ray Optical Systems). CRADAs and consortia are currently in place on combinatorial methods and polymer characterization.

In order for the division to further enhance the effectiveness and relevance of its work, the panel repeats its recommendation that a sincere effort be undertaken to encourage staff members to utilize the NIST Industry Fellows Program. This division plays an important role in providing standard methods and materials to U.S. industry, but most NIST researchers do not have a personal understanding of the challenges faced by their customers. While interactions in professional societies and conferences and visits by industrial customers provide a limited perspective, nothing can replace having NIST researchers spend even short periods of time at a customer site. The panel recognizes that utilizing the Industry Fellows Program is not always easy, but by being flexible in assignment duration, rewarding researchers for their participation, and setting specific division and CSTL goals for success, the program can be used more successfully. Industry utilizes such programs; CSTL can do so as well.

The division is very visible both nationally and internationally. The professional staff publishes its work extensively in prestigious scientific journals (80 publications in FY 2001); organizes and sponsors conferences and workshops (7 in FY 2001); and presents at major conferences, often as invited speakers (94 presentations in FY 2001). Staff members produce and maintain Web-distributed databases that are widely used by a variety of technical communities. SRD 20 (X-Ray Photoelectron Spectroscopy Database) alone produces more than 30,000 hits per month! The panel commends the division for greatly improving the accessibility and appearance of its Web site.

The ongoing division programs are also clearly focused on the needs of NIST's customers in other government agencies. Staff meet regularly with their colleagues in organizations such as EPA, DOD, and the U.S. Department of the Treasury to ensure that the division has the input it needs to fulfill the part of its mission directed toward supporting national security and the environment. Specifics of program relevance and the mechanisms that the division uses to stay aware of customer needs are discussed below.

The panel is pleased to see that the division staff have thought about how to meet customer needs for well-characterized materials that can substitute for completely characterized SRMs during the long (3 to 7 year) SRM development period. The new intercomparison materials (IM) project will allow the division and CSTL to respond more quickly to customer needs. Examples of IMs that might have strong impact include additional implant materials (boron, arsenic, and phosphorous in SiGe or silicides), particles, thin films (dielectrics on silicon), and real dust samples.

The division has shown the ability to stop work when a project fulfills the requirements of its customers or lacks further driving force. Examples of the former are the work on electron microprobe homogeneity standards and the generation of index of refraction standards; examples of the latter are synchrotron-based measurements of nitrided gate dielectrics. And the division can change the direction of a project when required to do so by its customers: future software development for image processing using lispix (a public domain image analysis program) and the desktop spectrum analyzer are being converted from Macintosh to PC platforms. More information and data are being distributed in electronic format using Web sites instead of being sent as individual copies. This maximizes the impact and effectiveness of dissemination of the division's research results. The panel recommends that the division continue to evaluate the full scope of its program in order to stay focused on highest-priority work.

The activities of the Atmospheric Chemistry Group have provided information that is clearly relevant to regulators seeking to formulate air quality strategies and to establish compliance with air quality and emissions standards. Because its expertise is complementary to the broad spectrum of atmospheric aerosol measurements, it is critically important that a group focused exclusively on atmospheric chemistry collaborate within the community of atmospheric scientists to have significant impact. The Atmospheric Chemistry Group continues to make progress in this regard through collaboration with EPA on the development and application of measurement techniques and calibrations.

The panel recognizes the Atmospheric Chemistry Group's effort over the past year to identify an environmentally relevant research agenda within its reach and to build to critical mass. In September 2001, the Workshop on Atmospheric Measures and Standards: Improving the Scientific Base for Informed Decisions on Atmospheric Issues was organized and hosted by the division. Attendees were

TABLE 4.4 Sources of Funding for the Surface and Microanalysis Science Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	4.6	4.7	5.3	5.3
Competence	0.4	0.4	0.2	0.2
ATP	0.4	0.3	0.3	0.2
Measurement Services (SRM production)	0.1	0.1	0.0	0.1
OA/NFG/CRADA	2.9	5.7	5.1	3.7
Other Reimbursable	0.3	0.3	0.2	0.1
Total	8.7	11.5	11.1	9.6
Full-time permanent staff (total)[a]	36	36	36	38

NOTE: Sources of funding are as described in the note accompanying Table 4.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

solicited from key government agencies (National Oceanic and Atmospheric Administration [NOAA], EPA, Tennessee Valley Authority), industry (Ford Motor Company, ExxonMobil, Northrop Grumman Corporation), universities, and other interested organizations. Key gaps in measurement technology and standards were identified, but no action plan has yet been developed.

Division Resources

Funding sources for the Surface and Microanalysis Science Division are shown in Table 4.4. As of January 2002, staffing for the division included 38 full-time permanent positions, of which 35 were for technical professionals. There were also 8 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The division's operational budget has remained essentially flat over this time period. The increase observed in FY 2000 and FY 2001 was due to one-time grants for major equipment from the division's other agency (OA) funding sources.

The quality of the personnel in the Surface and Microanalysis Science Division continues to be outstanding. In general, the staff think that the work they do is important and interesting and that it contributes to fulfilling the NIST mission; the morale is high throughout most of the division. In particular, the younger members of the staff believe that they are an important part of NIST. They appreciate the active mentoring they receive from more-senior division scientists.

Although the quality of people is extremely high, there do not appear to be enough technical staff members to fully exploit the capabilities of their equipment and the needs of the division's customers. For example, it appears that the work on radical reactions with surfaces did not end from a lack of customer need but because of the disappearance of key research personnel. The relatively flat budgets experienced by the division, and by NIST as a whole, over the past several years have made it difficult to bring in new staff. However, it is young scientists, hired now, who are needed to lay the foundation that will enable the division to continue to turn out high-quality technical results with an impact on industry and the U.S. public. While the panel is particularly impressed by the enthusiasm and qualifications of the younger people currently on staff, the division must continually freshen its mix of personnel. Turnover is very low, mainly occurring because of retirements, but limited resources make it a challenge for division management to bring in necessary new hires. Only one new technical professional was hired in the division this year, and the division will probably lose two promising postdoctoral researchers at the end of their terms in FY 2002 because appropriate openings on staff are not available. The division, CSTL, and NIST run the risk of losing fresh ideas and future technical leaders if they cannot find a method to continually update the staff.

In addition to not being able to retain new, young staff members, the division has not hired any new support staff in the past several years. There are no dedicated Web programmers, electronics specialists, machinists, or equipment maintenance specialists. In such a situation, there are two possible consequences: (1) important tasks will not be completed, or (2) the professional staff will be forced to take time away from their primary project-oriented duties to carry out key support tasks. Web programming falls into the first category; the panel commends the division for significantly improving its Web site during the past year but knows that this was done by existing technical professionals at the expense of their regular research work. Caring for laboratory instruments falls into the second category; routine equipment maintenance is being done by technical professionals who should be focused on new ways to use the equipment instead of on how to keep the equipment going. The panel once again encourages division and laboratory management to consider acquiring dedicated support staff for the purpose of ensuring that key tasks get done and that technical staff can operate with maximum productivity.

The morale of the Atmospheric Chemistry Group is suffering under the uncertainty of its future technical direction. The panel is very concerned that the staffing resources of this group are not sufficient to effectively execute an environmentally significant research agenda, despite an effort over the past year to identify a research agenda within the group's reach. This is not a new concern; it has been raised in the last two reviews. In light of the complementary analytical strength of the other groups within the Surface and Microanalysis Science Division, the panel sees an opportunity for the division to achieve its environmental objectives by blending the people and key research objectives of the Atmospheric Chemistry Group into the other three groups within the division. For example, within the framework of CSTL's focus on environmental issues (FY 2001: Environmental Measurements; FY 2002: Environmental Technologies), group members might enhance research directed at the chemical speciation of single particles within samples having high particle-numbers and also enhance research on the complementary algorithms for data analysis. The development of those techniques to resolve individual particle information in airborne samples could provide critical new information to resolve emission sources of airborne particulate samples. With the opportunity to leverage expertise and resources in the complementary groups within the Surface and Microanalysis Science Division, critical mass for sustained progress might be attained. Other corrective action plans undoubtedly merit consideration as well, but the panel is confident in its conclusion that laboratory and division management must address the issues of the size and focus of this group, either by giving it the resources and direction to succeed, or by reorganizing the critical activities into other CSTL groups.

In general, the division's instrumentation resources adequately support the technical programs. Capital equipment needs are carefully analyzed, and instruments are acquired in a systematic and timely fashion. OA funding is used to acquire major pieces of equipment such as the new, dynamic SIMS instrument and the x-ray photoelectron and Auger electron spectrometer; these tools are then leveraged across many research efforts. As a result, the division has a unique collection of state-of-the-art instrumentation, especially in electron microscopy, secondary ion mass spectrometry, near-field probes, and laser/surface probes.

The lack of a state-of-the-art focused ion beam (FIB) sample preparation system remains a noticeable gap in the division's resources. As discussed in last year's report, FIB technology remains an essential technique for cross-section and thin-section preparation of samples to be used in scanning electron and transmission electron microscopy. It is increasingly used in manufacturing processes for thin-film heads on disk drives and in MEMS structures. Unfortunately, little is known about the mechanisms involved in the high-energy (>30 keV) ion sputtering used in FIB, and the potentially negative impact of these mechanisms on sample composition and structure is not known. NIST is ideally situated to pioneer this research, and the panel again encourages the division to quickly build a coalition to acquire a commercial FIB system and, just as importantly, the required human resources to perform research in FIB sample preparation methods and materials modification applications. If action is not taken in the next fiscal year, NIST runs the risk of missing the opportunity of meeting an important need of U.S. industry. The panel suggests that alternative methods of funding—including collaborations with ion beam research groups outside of NIST but in the local area (for example, at UMD)—be explored to bring in equipment and people in a timely manner.

Physical and Chemical Properties Division

Technical Merit

According to division documentation, the mission of the Physical and Chemical Properties Division is to serve as the nation's reference laboratory for measurements, standards, data, and models in the areas of thermophysics, thermochemistry, and chemical kinetics. 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 located at Boulder—the Thermodynamics Research Center, Membrane Science and Technology, and Properties for Process Separations.

The programs of this division comply with the primary NIST mission to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. Each group in the division has ties to appropriate industries, and the division as a whole maintains a desirable balance between the programs that support shorter-term industrial needs and the research that will allow NIST to fulfill longer-term national science and technology requirements. Excellent balance also exists between experimental and theoretical expertise in the research programs. The division conducts work of unsurpassed quality in fundamental measurements of thermophysical and thermochemical properties. A key factor contributing to the value of the division's work is its outstanding researchers. Selected highlights of these programs are presented below.

The panel commends the Physical and Chemical Properties Division for its excellent balance between experimental and theoretical expertise in all areas of its research program. The panel notes particularly the continued emphasis on maintaining the unique experimental capabilities of the division. This is important, as experimental work continues to be deemphasized throughout the thermodynamics community, as reported in NIST Special Publication 975.[4]

[4]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Report on Forum 2000: Fluid Properties for New Technologies—Connecting Virtual Design with Physical Reality,* NIST Special Publication 975, National Institute of Standards and Technology, Gaithersburg, Md., 2002.

The Computational Chemistry Group has made excellent progress since it was founded in 1997. The group aims to provide computational chemistry-related data, benchmarks, and validation of methods to U.S. industry and academic researchers. A Virtual Measurement System is being explored for chemical kinetics that will allow accurate prediction of rate constants, including estimates of uncertainties, using theoretical methods. The results of these calculations are compared with experimental data provided by the Experimental Kinetics and Thermodynamics Group. The panel commends the synergism between these groups. Significant progress has been made in the past year in improving the understanding of proton tunneling. Research into isopotential searching to predict paths of unknown reactions has progressed to alpha testing in industry and academia. This technique has identified a potential new path for the decomposition of the explosive RDX, which suggests new strategies for detecting concealed quantities of this compound (a homeland security initiative). An excellent example of the pivotal role that the Computational Chemistry Group can play is the Fluid Properties Simulation Challenge that the group has helped organize over the past year. Participants from industrial and academic research laboratories studying molecular modeling and simulation exchanged ideas in a June 2001 NIST workshop on how to create a set of problems related to fluid properties in order to stimulate research on validating predictive molecular simulations. The contest to solve these problems is currently under way and will conclude in the fall of 2002.

The Experimental Kinetics and Thermodynamics Group provides reliable kinetic and thermodynamic data pertaining to industrial processes, environmental chemistry, energy efficiency, and fire suppression. Studies of the physical properties of ionic liquids and measurement of rate constants of fundamental chemical reactions in these liquids are under way. Ionic liquids are nonvolatile, nonflammable, recyclable solvents for polar and nonpolar compounds. They have been proposed as "green" solvents.) The division's research will provide essential data required to develop industrial processes exploiting the unique properties of ionic liquids. The division has initiated an examination of the chemical kinetics and mechanisms of combustion of real fuel mixtures instead of simple, one-component surrogates. This will provide information critical to an understanding of the generation of toxic pollutants and particulates in practical fuel mixtures. Rate constants for the reaction of OH with halogenated organics of atmospheric importance have been measured with unprecedented accuracy, providing new insights into reaction mechanisms, rigorous tests of kinetics theory, and tests of *ab initio* calculations by the Computational Chemistry Group. The division's Web-based Chemical Kinetics Database (http://kinetics.nist.gov) continues in beta testing. Targeted evaluations of selected rate constants for chlorination chemistry and data related to small hydrocarbon radical chemistry have been added to the database this year. The panel applauds the division's efforts on this database, which is critical to the more efficient design of industrial chemical processes. However, the kinetic rate constants in the database have not been updated since mid-2000 because of the lack of funds. This database should be a high priority for the division, and it is important to fund the work necessary to complete the full public release and to maintain an up-to-date database.

The Chemical Reference Data and Modeling Group, which compiles, evaluates, correlates, and disseminates Standard Reference Data, has had another productive year. It released the seventh edition of the *NIST Chemistry WebBook* (http://webbook.nist.gov). In FY 2001, the number of chemicals included in the *WebBook* increased by 11 percent to more than 40,000, and a subset of the Thermodynamics Research Center (TRC) data was added. The *WebBook* is accessed by 10,000 to 20,000 users per week, of whom 50 percent are return users, demonstrating the value of this tool. The division has begun work with academic and industrial partners to provide direct machine access to *WebBook* data using computer programs that reside on a user's machine.

The division has completed evaluation of 57,000 mass spectra received since the last release (1998) of the NIST Mass Spectral Database for gas chromatography (GC)/mass spectrometry (MS) analyses, and a new release is planned for 2002. This analysis tool has enormous practical application in industry. The NIST Automated Mass Spectral Deconvolution and Identification Software (AMDIS) is also of great value in general analytical chemistry, particularly in the detection of chemical weapons. This makes implementation of the international Chemical Weapons Treaty easier and more effective technically. The panel also applauds the initiation of cross-divisional efforts with the Analytical Chemistry Division to devise mass spectral methods for the detection of biological weapons, providing support for the NIST homeland security strategic focus area.

The Properties for Process Separations project provides critically evaluated data and models for industrially important processes including distillation, adsorption, and supercritical fluid extraction. Gas chromatographic techniques developed in this project were recently applied to the study of natural gas odorant adsorption on surrogate soil surfaces. These data show that sulfide odorants are more likely to be adsorbed (fade) than are mercaptan odorants. This finding has significant implications for pipeline leaks below ground level. The kinetics of the hydrolysis of carbonyl sulfide to hydrogen sulfide have been measured in a multiyear study. A key finding is that the reaction rate to H_2S is very slow at typical temperatures, and thus hydrolysis of carbonyl sulfide is an unlikely route to fugitive H_2S in liquid petroleum gas. This project has led to the development of a new patented apparatus. The project's new initiative to use in situ Fourier-transform infrared (FTIR) spectroscopy to collect vapor-liquid equilibria data, particularly on mixtures that are reactive, corrosive, or toxic, is in the laboratory testing phase. Data on this class of difficult mixtures will be measured at temperatures to 450 K and pressures to 20 MPa.

The Theory and Modeling of Fluids Group provides model-based correlations and predictions, evaluated standard reference data, data on water and aqueous systems, and computer simulation of solid-fluid equilibrium. The group made significant progress in ab initio quantum mechanical routes to technologically important properties of gas-water mixtures. These data are needed for many applications, such as the engineering design of combustion turbines. Work on water-argon systems and systems of the other noble gases is complete. The project's focus will now shift to water-nitrogen and water-hydrogen. The group completed an important study on aircraft fuel tank safety. The study produced detailed liquid-vapor phase equilibria on Jet-A fuel through the use of a Peng-Robinson equation-of-state in an extended corresponding state method. This work is part of a collaboration with the Building and Fire Research Laboratory that aims to recommend improved regulations for the inerting of fuel tank vapor spaces, venting requirements, and jet fuel formulations.

The Membrane Science and Technology project provides significant resources for industries that seek more efficient chemical and pharmaceutical separations and waste-reduction processes through membrane technologies. This year, a researcher developed a new apparatus to continue the study of high-throughput membrane transport, funded through the NIST Advanced Technology Program. This enhanced apparatus uses sensitive in-line fluorescence detectors and a fiber-optic multiplexer to provide in situ analysis of eight samples simultaneously. The high-throughput work is relevant for efforts to measure fundamental diffusion and solubility data and to elucidate transport mechanisms. Further work has also been done on data measurement systems for pressure-driven membrane separations. The panel is concerned, however, that the division is unable to maintain a critical mass of staff for the project.

The Experimental Properties of Fluids Group measures high-accuracy, comprehensive thermophysical and transport property data on pure fluids and mixtures using state-of-the-art, and often unique, laboratory apparatus. This group collaborates particularly closely with the Theory and Modeling of Fluids Group on projects related to alternative refrigerants and natural gas technology. A significant example of this collaboration is the completion and imminent release of the refrigerant properties database, REFPROP7 (http://www.nist.gov/srd/nist23.htm). This database update incorporates new measured data and an enhanced user interface with higher-speed calculations. The group continues work on enhancing its measurement capabilities by completing the installation of a double-sinker densimeter to measure liquids and dense gases, particularly replacement refrigerants. This unique apparatus will provide primary standard density data by reference to a silicon standard. During the past year, the group completed measurements on the heat capacity of refrigerant R125 near the liquid-vapor critical point, and pressure-density-temperature data for R410A refrigerant blend. These data will facilitate the development of new refrigerant systems that can be used under extreme conditions without major losses in capacity and efficiency.

Significant and rapid progress in restoring full and improved operations in the Thermodynamics Research Center was made during the past year after its transfer to NIST Boulder in mid-2000. A major new initiative was completed with the establishment of the TRC Data Entry Facility. This facility, which uses new, interactive Guided Data-Entry software, ensures that all relevant experimental data are captured and added to the TRC SOURCE data file. In addition, a new Data Quality Program has been designed to control source data quality at all stages of data entry, evaluation, and database management. More than 850,000 numerical values on 16,400 chemical substances, 9,000 mixtures, and 3,800 reaction systems are available in the TRC SOURCE database. These data will be used to support relevant NIST and CSTL missions. 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.

The Cryogenic Technologies Group conducts research to help commercial firms and government agencies develop and improve technologies for the $10 billion cryogenic process and product industry. Databases, laboratory measurements, cryogenic process models, and technology transfer are the key elements of this program. A significant recent advance is the use of photo-etching to create the flow channels in a miniaturized parallel plate heat exchanger. This will facilitate fundamental studies in cryogenic heat transfer.

Program Relevance and Effectiveness

The panel is pleased by the Physical and Chemical Properties Division's efforts to ensure that its programs are relevant to the needs of its customers. The division employs a variety of mechanisms to gather input on current and planned divisional activities, particularly encouraging suggestions and requests from external organizations. Division personnel interact with people from other institutions at standards committee meetings, technical conferences, road-mapping activities, professional society and committee meetings, and trade organization events. Staff take lead roles in organizing many of these gatherings and often hold them at NIST. For example, in FY 2001, the division organized the 5th International Conference on Chemical Kinetics, the International Association for the Properties of Water and Steam Annual Meeting, and a Workshop on Predicting the Thermophysical Properties of Fluids by Molecular Simulation. Division personnel have informative relationships with guest researchers and collaborators from industry and universities.

The division's programs have an impact on a wide array of industries and research communities. Programs often bridge the gap between the short-range research goals of industry and the long-range, open-ended inquiries commonly pursued in universities. Staff awards demonstrate the value placed on the division's work. In FY 2001, a staff member received two NASA Group Achievement Awards for the development of the Earth Science Research Strategy and for contributions to the 1999/2001 Stratospheric Aerosol and Gas Experiment III Ozone Loss and Validation Experiment. Another staff member received the Robert Vance Award from the Cryogenic Society of America for advancements in the field of cryogenics. The division's products include databases that scientists use to develop computational models and analytical techniques for industrial, environmental, and fundamental chemistry applications. The panel commends the division 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 produce data and the underlying understanding that allow the division to make high-quality information readily available to technical communities.

The division's work also has significant impact in international standards activities. Division staff are active in a number of organizations working on alternative refrigerant standards, including the International Energy Agency, the International Union of Pure and Applied Chemistry, and the International Organization for Standardization. In addition to data-based products and committee activities, the division provides unique standards and services regarding fluid flow under cryogenic conditions.

The Physical and Chemical Properties Division makes strong and well-directed efforts to convey its research results to the relevant scientific and engineering communities. It effectively utilizes basic tools such as publications and presentations. In FY 2001, division staff published 158 papers, primarily in peer-reviewed journals; made 135 presentations (22 invited) at scientific meetings; and served on 67 national and international scientific committees. The extent of the division's reach into relevant communities can be seen in several other statistics. The *Chemistry WebBook* was visited from more than 350,000 unique Internet addresses last year (an increase of 40 percent). Roughly one-half of all GC/MS instruments sold worldwide include the Mass Spectral Database; 2,500 copies of this database are sold annually. The 5th International Conference on Chemical Kinetics organized and hosted by the division attracted 150 participants from 13 countries spanning the globe. The division's unique Workshop on Predicting the Thermophysical Properties of Fluids by Molecular Simulation—goals of the workshop were to identify prediction needs that could be satisfied by molecular simulation and to drive research to ensure that simulation will be a relevant tool in the long term—was attended by 42 persons from industry and academic institutions. 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.

Because of their high reliability, the advanced pulse tube refrigerators developed in the Cryogenic Technologies Group are used across a wide spectrum of applications, from radio astronomy to superconducting electronics and superconducting motors. This reliability results from the complete absence of moving parts such as pumps and compressors. The interest in this technology is evidenced by the large number of awards, invited or plenary lectures, and short courses given by the group's staff. More than 29 cryogenic companies have been customers of the group through consultations and CRADAs.

The panel looks for continued improvement in Web access to the products produced by the Physical and Chemical Properties Division. Coordinated access to the data in the *Chemistry WebBook* and the TRC database should be a goal, as acknowledged by the division. The panel recommends investigating ways to significantly expand the type of data available through the *Chemistry WebBook* (e.g., to include mixture data) using TRC resources. In addition, the panel strongly recommends that the division addresses the issue of cost recovery for databases in general, possibly through a subscription mode for full access to the data via the Web.

Division Resources

Funding sources for the Physical and Chemical Properties Division are shown in Table 4.5. As of January 2002, staffing for the division included 55 full-time permanent positions, of which 46 were for

TABLE 4.5 Sources of Funding for the Physical and Chemical Properties Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	9.1	8.7	6.9	7.0
Competence	0.1	0.0	0.0	0.0
ATP	0.4	0.4	0.6	0.7
OA/NFG/CRADA	3.5	2.9	2.8	3.2
Other Reimbursable	0.3	0.3	2.6	2.4
Total	13.4	12.3	12.9	13.3
Full-time permanent staff (total)[a]	65	64	56	55

NOTE: Sources of funding are as described in the note accompanying Table 4.1.
[a]The number of full-time permanent staff is as of January of that fiscal year. The drop in staff between FY 2000 and FY 2001 resulted from the move of the Fluid Science Group to the Process Measurements Division.

technical professionals. There were also 19 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The division's STRS resources are basically flat, which requires division management to obtain additional resources from other sources or to terminate projects and reallocate existing resources to ensure the impact of 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 22 percent in FY 2001, essentially unchanged from FY 2000. The current level is high enough to demonstrate that the division's 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. Other divisional products are provided to customers free of charge over the Web, including the *Chemistry WebBook* and the Chemical Kinetics Database. The panel notes that the information in these databases is critical to many scientists, and NIST might consider imposing a user fee for access, especially since the resources to support the project are limited. In particular, funds for support of the Chemical Kinetics Database are so tight that the database cannot be kept current, as discussed earlier. Users might welcome paying a fee in order to guarantee that the databases are current and provide increasingly useful features.

The staff in Gaithersburg and Boulder are a key asset of the Physical and Chemical Properties Division. Many examples of significant individual accomplishments by staff attest to the high quality of the team. One staff member was elected a fellow of the American Physical Society for outstanding contributions toward improved understanding of structural and dynamic properties of simple and complex liquids. Two others received the 2001 Russell B. Scott Award for the best paper presented at the Cryogenic Engineering/International Cryogenic Materials Conference. NIST-wide awards (the Jacob Rabinow Applied Research Award and the Judson French Award) and a Department of Commerce Bronze Medal were also conferred on division members. Division personnel are lead editors of two major journals (*International Journal of Chemical Kinetics* and *International Journal of Thermophysics),* and associate editors of 14 other publications. These awards and positions of responsibility demonstrate the regard in which division staff are held by their peers in the scientific and industrial communities.

Despite major improvements, serious issues remain within the Boulder facilities. Building 24 lacks an elevator to provide access to the second floor where most of the division space is located. The only access other than by the stairway is via a forklift. The division states that an elevator is "on the site master plan but is at least a year or two away." The panel believes that the installation of elevators must be moved to the highest priority in order to meet current access standards in both Building 24 and Building 2. The heating, ventilation, and air-conditioning system in Building 24 is not adequate for laboratory ventilation or temperature control, and no plans are in place for improvement. A plan should be developed immediately to ensure the interim safety of workers in the chemical laboratories and to bring the laboratories up to currently accepted standards.

Staff in Gaithersburg appear satisfied with their physical facilities, although the panel continues to have concerns as noted in the FY 2001 report. As acknowledged by the division, in some laboratories air cleanliness, dust control, and air filtration are still insufficient; the quality, capacity, and reliability of the power supply are still problematic; and the exhaust and ventilation systems are still inadequate. While the current quality of the Gaithersburg facilities is generally comparable with that at research universities, these deficiencies will eventually interfere with the division's ability to perform the type of high-precision experiments that are needed to supply industrial and academic researchers with the accurate, high-quality data that are the division's hallmark. The panel urges that a detailed plan be developed for improvement of division facilities.

No capital equipment funding issues appear to be limiting the initiatives undertaken by division scientists in Gaithersburg or Boulder. In fact, some of the apparatus in the division are not even available in industrial laboratories.

The division's research is split equally between the Boulder and Gaithersburg sites. The panel is particularly pleased with the concerted effort made during the past year to familiarize personnel at each site with the research carried out at the other. This has involved regular intradivision seminars held by teleconference and visits between sites. Close coordination is required to maximize research effectiveness within the division, and the panel commends this effort. With the retirement of the current division chief, CSTL management should consider the structure of the division and the effect of the geographical split on the coordination and efficacy of division research programs.

Analytical Chemistry Division

Technical Merit

The Analytical Chemistry Division states its mission as serving the nation's premier reference laboratory for chemical measurements and standards to enhance U.S. industry's productivity and competitiveness, assure 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 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 Spectrometry and Microfluidic Methods, and Nuclear Methods.

During FY 2001, division staff members won several awards, most notably, two LabAutomation

Conference Poster Awards, an IR-100 Award, and an award for Distinguished Service in the Advancement of Analytical Chemistry by the American Chemical Society.

The Molecular Spectrometry and Microfluidic Methods Group demonstrates a high degree of technical expertise applied to a wide range of meaningful programs relevant to molecular spectroscopy and technology associated with microfluidic devices. In all of the programs, there appears to be a concerted effort to employ cutting-edge technology, but at the same time, there is a notable willingness to look outside NIST for collaboration and support when it is necessary. The quality of the technical effort is validated by the high level of acceptance of the products and the publication and dissemination of information in leading peer-reviewed journals. In FY 2001, the group filed five new patent applications. In addition, during the year, two new patents were issued to the group.

The Molecular Spectroscopy and Microfluidic Methods Group has demonstrated its productivity and innovation with its work on design and applications of plastic microfluidics systems. The decision to concentrate effort on polymer-based substrates is laudable, and the progress made in characterizing fluid flow and temperature measurement in the microstructures is most impressive. This area alone resulted in eight peer-reviewed papers in FY 2001. An important element of this group's success has been its willingness and ability to interact with other groups within CSTL and NIST.

The Spectrochemical Methods Group conducts research involving the development, critical evaluation, and application of methods for the identification and measurement of inorganic chemical species using optical, mass, and x-ray spectrometries. The instrumentation capabilities of this group include inductively coupled plasma (ICP) and thermal ionization mass spectrometers, wavelength and energy dispersive x-ray spectrometers, ICP optical emission spectrometers, and a glow discharge optical emission spectrometer.

The most significant development from the Spectrochemical Methods Group in FY 2001 was a comprehensive method for the accurate determination of mercury in a wide variety of materials. The new, cold vapor isotope dilution inductively coupled plasma mass spectrometry (CV-ID-ICP-MS) methodology is a relatively straightforward, but highly versatile, approach for elemental mercury determinations. The technique is built on the combination of this group's expertise in ID-MS as a benchmark method, ICP-MS detection power, and well-known cold vapor generation methods. This very important development was acknowledged by *Research and Development* magazine's 2001 R&D 100 award. Seven NIST SRMs for coal have been certified for their mercury content by this method. This methodology has also been incorporated at the NIST Hollings Marine Laboratory in Charleston, South Carolina, where it will be an important tool in the archiving of marine specimens.

The group has extended the ID-ICP-MS method to determinations of iodine. Iodine deficiency has been noted as a major problem by the World Health Organization. Unfortunately, few reference materials exist for iodide content in body fluids. The use of ID-ICP-MS has allowed the certification of iodide content in SRM 2670a Toxic Elements in Freeze-Dried Urine. Future work will implement the same procedure for determinations in blood serum. A number of otherwise-difficult determinations were performed employing high-resolution (HR) ICP-MS and ICP-MS operating under so-called cold plasma conditions. In collaboration with the Organic Analytical Methods Group, HR-ICP-MS was employed as an element-specific detector for iron speciation studies in body fluids. Because ^{56}Fe is the most abundant isotope of iron, the presence of isobaric interferences is problematic for sensitive detection. In the case of ICP-MS, the large abundance of ArO^+ at 56 daltons is a perennial problem. The resolving power of the Finnigan Element HR-ICP-MS allows these determinations to be made without the presence of the ArO^+ background. Cold plasma conditions are a useful means of drastically reducing the contributions of Ar-related ions to ICP-MS spectra. Specifically, cold plasma operation allows sensitive determinations of Ca and K, which are usually not accessible at all due to the suite of Ar isotopes in the same mass region. Measurements of Ca and K have been performed on reference materials in support of the National Reference System for the Clinical Laboratory Program.

The Spectrochemical Methods Group is working to certify a new, silica-on-filter reference material. Crystalline silica inhalation is a major health risk in the mining and construction industries worldwide, but the lack of reference materials is a major hindrance to implementation of more stringent standards and their enforcement. The group is working with the Occupational Safety and Health Administration, the National Institute for Occupational Safety and Health, and the Mine Safety and Health Administration to develop an SRM that is appropriate for instrumentation calibration. Sample preparation methods have been evaluated for both ICP optical emission spectroscopy and ICP-MS. The production and certification of the SRM is scheduled for FY 2002.

Research activities in the Nuclear Methods Group are focused on the science supporting the identification and quantification of chemical species by nuclear analytical techniques. Current research activities involve the full suite of nuclear analytical techniques, including instrumental and radiochemical neutron activation analysis (INAA and RNAA), prompt gamma-ray activation analysis (PGAA), and neutron depth profiling (NDP). In addition, the group is developing analytical applications of neutron-focusing technology. The measurement capabilities that reside within this group provide an excellent complement to those in the Spectrochemical Methods Group in that they depend on characteristics of the nucleus of the element rather than on the electron shells probed in spectrochemical techniques, and therefore are insensitive to the chemical state. Nuclear analytical methods are also nondestructive and do not require sample dissolution. The Nuclear Methods Group may be underutilized relative to its capabilities to provide an independent assay for work throughout the division.

INAA and RNAA are powerful reference techniques that have been used at NIST for many years. The instrumentation and methodologies have continued to evolve, providing increased sensitivity, specificity, precision, and accuracy. To that end, the Nuclear Methods Group has characterized the sources of error and imprecision to a very high degree of certainty. The group is putting particular effort into establishing the position of nuclear methods as primary methods of measurement. This requires a complete uncertainty statement written in terms of SI units, meaning that each step in the sample handling and each component of the measurement system must be characterized. In principle, a primary method is one in which analysis is possible without using a standard. Such methods are powerful tools in novel materials characterization and a vital component in the NIST SRM certification program.

INAA methods are now paying particular benefits in the characterization of sample homogeneity in small analytical specimens. Many analytical techniques employed for elemental analysis are based on the use of small sample quantities (i.e., 1 mg) in the solid form. These samples are then put into solution. In such situations, the degree of representation that the specimen has for the bulk of the sample comes into question. This is also true for Standard Reference Materials where elemental certification is based on the use of 100- to 500-mg quantities. To be truly valid for real-world situations, SRMs must be certified on the size scales to which they are applied. Taking advantage of the sensitivity and nondestructive nature of INAA, the use of this technique for homogeneity studies of small samples has been evaluated and implemented for the determining sampling characteristics for a number of environmental SRMs. The minimal analytical uncertainty associated with INAA allows extraction of the variability that is due to the material inhomogeneity from the observed total variability within a given set of measurements. This very important characteristic will be a valuable contribution to the certification of SRM 2783, Urban Air Particulate Matter on Filter. This particular SRM is the primary SRM for EPA's National Air Quality Program.

The capabilities of the Nuclear Methods Group in the areas of PGAA and NDP are of particular importance to U.S. industry and other government agencies. The capabilities are enabled by the NIST's Cold Neutron National Users Facility. PGAA provides unique information for analysis of light elements, particularly hydrogen. Nondestructive, matrix-independent measurements of hydrogen in diverse materials such as Nafion (ionomer) membranes used for fuel cells and in fundamental studies of embrittlement in metals and alloys are very important applications. PGAA is also used to advantage in a wide variety of polymers and refractory materials such as zeolites, for which sample dissolution for analysis is not an option. A wide range of elements, including lanthanides, can be determined in these matrices as well. Important instrumentation improvements now permit the focusing of the cold neutron beams down to 100 μm × 100 μm spot sizes for laterally resolved measurements. Depth-resolved analyses are possible using the NDP methodology for determinations in specialty materials. For example, in collaboration with the Army Research Laboratory, the group determined the percentage of boron in tungsten alloys, and a collaboration with Advanced Micro Devices used NDP for the analysis of boron in silicon matrices. The technique has also been used to determine the long-term stability of primary boron and lithium standards.

Research in the Organic Analytical Methods Group is directed toward the development, critical evaluation, and application of methods for the identification and measurement of organic and organometallic species using mass spectrometry and analytical separation techniques. These separation techniques include gas chromatography (GC), liquid chromatography (LC), supercritical fluid chromatography (SFC) and extraction (SFE), capillary electrophoresis (CE), and capillary electrochromatography (CEC).

Acquisition of an LC/MS/MS instrument during the past year increased the Organic Analytical Methods Group's capabilities for the determination of analytes of health, nutritional, forensic, and environmental importance, as well as for structural studies of natural products. A matrix-assisted laser desorption time-of-flight mass spectrometer (MALDI-TOF) system was obtained to characterize biomolecules. This instrument was acquired with support from the Defense Threat Reduction Agency in order to begin development of protocols for generation of mass spectra from bacteria. The combination of proteins produced by one species of bacteria differs from that of another. The MALDI-TOF system is used to generate a mass spectrum from the bacterial proteins to permit the identification of bacteria much faster than is now done by conventional approaches. This will be applicable to counterterrorism activities as well as to food safety. The MALDI-TOF system will also be used to characterize health status protein markers and proteins expressed by genetic modification of foods.

The Organic Analytical Methods Group's research in separation science continues to focus on investigations of the physical and chemical processes that influence sample retention in LC, GC, SFC, CE, and CEC. Results from these fundamental studies are used to design stationary phases tailored to solve specific separation and analysis problems and to assist in method development and optimization. Recently, the group explored a novel approach to the synthesis of LC stationary phases based on polymer immobilization. Polyethylene acrylic acid copolymers were immobilized on silica as an alternative to conventional silane surface modification chemistry. The resulting columns were evaluated for the LC separation of carotenoid isomers, and preliminary results indicate exceptional selectivity for this class of compounds. Research in chiral separations is continuing in several areas, using LC, CE, and GC. The determination of chiral drug species in hair samples using LC may permit environmental exposure to be distinguished from illicit use. In other studies, functionalized cyclodextrins have been evaluated as chiral selectors in CE. A capillary electrophoresis method with indirect detection was used to characterize the patterns of sulfate substitution of these materials. The selectors were then investigated as chiral additives in capillary electrophoresis. These studies emphasize the importance of the use of well-characterized selectors for reproducible results in chiral CE.

Research in organometallic speciation has continued, with improvements in the GC-atomic emission detection (AED) method for methylmercury and alkyltin species. The new approach involved derivatization and a solid phase microextraction step to concentrate the analytes prior to GC-AED analysis. This approach has been used to provide several SRMs for methylmercury in marine tissue. This same general approach has been used to measure butyltin species in several of the sediment-matrix SRMs. It should be emphasized that methods developed for heavy metal speciation are of key importance to directed work taking place in the Hollings Marine Laboratory.

Research activities within the Gas Metrology and Classical Methods Group are focused on gas metrology, classical wet chemical methods (gravimetry and titrimetry), coulometry, ion chromatography, and maintaining the theoretical infrastructure for pH and conductivity measurements.

Program Relevance and Effectiveness

The Analytical Chemistry Division provides traceability of chemical measurements used in programs of national and international importance through Standard Reference Materials, 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 measurement institutes. The division strives to ensure that the projects undertaken are responsive to the metrology needs of its customers, which include national and international industry, basic research communities, and other government agencies. It has been actively seeking out its customers, leading other metrology agencies, and fostering international partnerships. Examples demonstrating program relevance and effectiveness follow.

Increased requirements for quality systems documentation for trade and for effective decision making regarding the health and safety of the U.S. population have increased the need for demonstrating "traceability to NIST" and establishing a more formal means for documenting measurement comparability with standards laboratories of other nations and regions. During the past year, the division quantified more than 140 SRMs to address such needs. The division contributed to certifying 686 of the 1,400 NIST SRM chemical standards, and providing from storage >16,000 of the 32,000 NIST SRM units sold in FY 2001. The NIST-Traceable Reference Materials Program addresses the need for reference materials with 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. Eleven specialty gas companies worked with NIST to certify more than 8,500 NTRM cylinders of gas mixtures that have been used to produce more than 500,000 NIST-traceable gas standards for end users with a market value of approximately $110 million. Thirty-six NTRMs were value-assigned for four specialty gas companies during FY 2001.

International agreements and decisions concerning trade and social well-being are increasingly based on mutual recognition of measurements and tests between nations. The division has taken a leadership role in 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). The CCQM has formed seven working groups responsible for selecting and overseeing the operation of key comparisons that address chemical measurement-related issues important for international trade and for environmental, health, and safety-related decision making. The Analytical Chemistry Division is leading activities within five of the seven working groups. During FY 2001, the division participated in 25 CCQM comparison studies, serving as pilot laboratory in 13 of them. During the past year, six intercomparison exercises were developed to assess the proficiency of SIM NMI's and their designated collaborators for addressing chemical measurement problems within their regions and in the Americas. The Analytical Chemistry Division has established agreements with the Chemical Metrology Working Group leaders to allow non-CCQM member countries within SIM to participate in such studies. Division members are working within the framework of the Cooperation in International Traceability in Analytical Chemistry to establish practical, metrologically sound, vertical traceability links between the NMIs and chemical testing laboratories in various countries and regions around the world.

The division provides chemical measurement quality assurance services in support of other federal and state government agency programs. During the past year, the division conducted 25 projects with 11 federal and state government agencies. Division members had technical interactions that involve laboratory research and measurement activities with more than 20 professional organizations and societies, including the American Industry/Government Emissions Research consortium (AIGER), the American Association for Clinical Chemistry, the American Society for Testing and Materials, the Certified Reference Materials Manufacturers Association, the National Food Processors Association, the National Council on Clinical Chemistry, and the National Environmental Laboratory Accreditation Council.

The Molecular Spectrometry and Microfluidic Methods Group has several programs and projects directed at providing standards for spectroscopy. An essential program involving cooperation between the three NMIs of the North American Metrology Organization (NORAMET) (Canada, United States, and Mexico) is based on the production of holium oxide solution reference materials for wavelength calibration in molecular absorption spectrometry. Another project seeks to develop a fluorescein solution fluorescence standard for use in flow cytometers, fluorimeters, fluorescence microchip readers, and other similar instruments. A new SRM (SRM 2241) provides a relative intensity standard for Raman spectroscopy using 785-nm excitation. This SRM will provide the analytical Raman community with practical methods to standardize spectral data. Another spectroscopy standardization effort has been directed at providing ultraviolet (UV), visible (VIS), and near-infrared (NIR) wavelength standards for transmission measurements. The aim of these standards is to provide SRMs intended for verification and calibration of spectrophotometers operating in the transmission mode. The development of these new standards, especially those for fluorescence measurement, is laudable.

The Molecular Spectrometry and Microfluidic Methods Group has provided the spectroscopy community with a new product, SpectroML, that is an extensible markup language for molecular spectroscopy data. This is a Web-based mechanism for interchanging UV and VIS spectral data generated on different spectrophotometers. The effort is well supported by industry and key professional committees.

The Molecular Spectrometry and Microfluidic Methods Group has carried out research on and developed standards supporting forensic measurements of gunshot residue. The aim of this project is to provide a gunpowder reference material for quality assurance in the detection and characterization of explosives. The project is relevant to the NIST homeland security SFA and should prove extremely valuable.

The Spectrochemical Methods Group was very active in international standards activities during the past year. The group participated in five pilot and key comparisons of the Inorganic Working Group of the CCQM. The specific projects were (1) CCQM K-13, cadmium and lead content in sediment; (2) CCQM P-12, lead in wine; (3) CCQM P-26, sulfur in fuel; (4) CCQM P-14, calcium in serum; and (5) CCQM P-29, cadmium in rice. This group has taken significant leadership positions in many other international interactions, reflecting the high esteem in which it is held by the community.

The Organic Analytical Methods Group's research activities in organic mass spectrometry have focused on the development of techniques for characterization and quantitative determination of proteins in biological matrices. Levels of specific proteins and other biomolecules in blood are indicative of certain disease; measurement of these health-status markers can permit more rapid diagnosis of disease with greater certainty than is possible by other methods. The United States spends $1.1 trillion per year on health care, approximately 15 percent of which is attributed to diagnostic measurements. Thus, the development of appropriate standards is of key consequence in economic and health-related matters. The group's priorities for SRM and measurement method development have been established by valuable consultation with numerous professional and government agencies. The technical impact of this work has been to provide a sound basis for the standards required by the diagnostic industry. The economic impact of these standards will come from the major role they will play in assuring the quality of health care measures and providing U.S.-based companies with the capacity to meet new European Union regulations. SRMs include glucose in human serum, drugs of abuse in hair, and troponin. Twelve health-status markers have been identified as the highest priorities for immediate studies. This year's research efforts have been directed toward the development of reference methods for troponin I (a new marker of myocardial infarction), thyroxine (a marker for thyroid function), cortisol (a marker for endocrine function), speciated iron (how iron is associated with proteins is important for elevated or low iron levels), 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 (a marker for prostate cancer). To this end, an interlaboratory comparison exercise of candidate troponin I reference materials was carried out in collaboration with the Troponin Subcommittee of the American Association of Clinical Chemists. Ten troponin I materials were evaluated by 13 manufacturers of immunoassays.

The Association of Official Analytical Chemists International has developed a nine-sectored triangle in which foods are positioned on the basis of their fat, protein, and carbohydrate content. NIST has been working with other government agencies and the food industry over the past several years to provide an increased array of SRMs to cover each sector, with values assigned for proximates (procedurally defined values for fat, protein, carbohydrate, and so on), fatty acids, cholesterol, vitamins, elements of nutritional interest, and so on. Concentration values in the food-matrix SRMs are assigned on the basis of a combination of measurements from NIST and interlaboratory comparison exercises involving approximately 20 member laboratories of the National Food Processors Association's Food Industry Analytical Chemists Subcommittee. SRMs for numerous analytes have been completed using chocolate, fish tissue, spinach, and peanut butter matrices.

The Gas Metrology and Classical Methods Group continues to be very active internationally in pH measurements. In FY 2001, it participated in a pH key comparison (CCQM-K17) and a phthalate buffer (pH 4.0) comparison and assisted the pilot laboratory of the German NMI in preparing the solutions for these comparisons. The group completed a SIM pilot study on pH (SIM QM-P4) with 16 participating laboratories in South America, Mexico, and the Caribbean. Members have continued to be active in IUPAC commission V.5, completing revisions to the pH document that will define the traceability of pH to the Bates-Guggenheim convention, thus ensuring continued traceability of pH to sound thermodynamic principles.

In collaboration with EPA and the remote-sensing community, the Gas Metrology and Classical Methods Group developed a quantitative database of infrared spectra. This database is required for establishing remote IR-based technology as a reliable tool for real-time monitoring of airborne chemical contaminants along plant boundaries and within plant facilities. Because the spectra are being prepared using NIST primary gas standards, well-defined traceability to NIST can be established for any subsequent field measurements. These spectra will be specified for use by industry in the new update of EPA method TO-16. At the present time, the group has released data for 40 compounds. The group is active in international ozone measurement activity, and it completed the upgrade of the EPA Standard Reference Photometer (SRP) network with new electronics. Many countries have expressed interest in receiving an SRP to provide traceability in ozone measurements, and Portugal, Spain, BIPM, and Brazil have ordered SRPs. Because of the strain this program places on resources, the division has agreed to transfer of the responsibility for world traceability for ozone to the BIPM in Paris, France.

The Analytical Chemistry Division promotes U.S. industry through the development of high-priority standards and through standards organizations such as ASTM. Over the past 2 years, the division developed the capability to produce low-concentration nitric oxide gas standards. These standards are required by the automotive industry in new-car development and for meeting new regulations in California, and they are needed by industry to meet new regulations covering stack gas emissions. This research has resulted in two new, nitric oxide gas SRMs, one at 0.5 ppm (SRM 2737) and one at 1.0 ppm (SRM 2738).

In July 2001, a meeting was held at NIST with representatives from AIGER to discuss research and standards needs to support emissions testing for the next generation of automobiles. AIGER is composed of the California Air Resources Board, the EPA, and automobile industry representatives (Daimler-Chrysler, Ford, General Motors).

Division management recognizes the changing demand for new SRMs and the need for advanced technologies to support the growing materials, biotechnology, and semiconductor industries as the U.S. and global economy improves. These complex commercial reference standards require an increase in effort from the Analytical Chemistry Division that can come about only by forming partnerships, as the Gas Metrology and Classical Methods Group has done with the NTRMs, or by selective postdoctoral hiring, or encouraging long-term guest researchers (from other agencies or from industry) and aggressively seeking increased external funding. In today's highly commercial environment, technical success must be tied to and directly quantified in terms of impact on the cost of a process, product, or market. An active part of each program's plan must be justified at the start with business and technical metrics. The end result of any new SRM, NTRM, or measurement technology should be an ongoing, quantifiable return to the commercial stakeholders. Such an impact argument needs to be developed by the researcher and to be widely publicized to best gain recognition from funding sources.

The panel finds that the division has not adequately addressed its Web site and overall Internet presence to the level needed for the appropriate global impact of its results on information exchange. The division indicated that, owing to lack of manpower and common software tools, and its perception of the value-added aspect of this task at this time, little to no added effort was put forth in FY 2001. The panel restates its recommendation that the division consider how best to apply current Web capabilities, until such time as a common software/Web protocol can be provided, to meet the needs of global technology and information transfer.

The programs within the Analytical Chemistry Division are critical to quantifying the value of international commerce via the SRM and NTRM standards. This laboratory is a national asset in terms of both the technical capability that it applies within the United States and internationally and its substantial impact on U.S. commerce. On the basis of this review, the panel sees the division as being highly effective in the means it uses to conduct and communicate its results to customers on a global basis, although tangible acknowledgment of the NIST impact by U.S. industry is disproportionally low.

Resources

Funding sources for the Analytical Chemistry Division are shown in Table 4.6. As of January 2002, staffing for the division included 67 full-time permanent positions, of which 61 were for technical

TABLE 4.6 Sources of Funding for the Analytical Chemistry Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	8.5	8.4	8.6	9.0
Competence	0.3	0.3	0.3	0.4
ATP	0.1	0.1	0.3	0.5
Measurement Services (SRM production)	2.2	2.2	1.6	1.6
OA/NFG/CRADA	2.0	2.4	2.9	3.0
Other Reimbursable	1.5	1.5	1.7	1.6
Total	14.6	14.9	15.4	16.1
Full-time permanent staff (total)[a]	66	68	69	67

NOTE: Sources of funding are as described in the note accompanying Table 4.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

professionals. There were also 25 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The current division technical staff is a responsive group of interactive teams fully capable of addressing the development and implementation of new measurement standards to serve the ever-changing world economy in emerging areas such as pharmaceuticals, foodstuffs, and microelectronic fabrication. As previously noted, recognition of staff scientists by peers outside NIST is high, as evidenced by awards to division members.

To utilize its limited resources better and to enhance staff satisfaction, the panel recommends that the division establish and encourage technical training and cross-training on its many analytical systems. This goal might be accomplished through a mentoring program or by self-help programs that are rewarded with added levels of responsibility. The division should foster and proactively manage interactions between the varied disciplines within NIST to form new dynamic work teams. Different technologists can see a problem from completely different angles, resulting in the use of alternative techniques that may produce cheaper, faster, or better results.

The division should also use recognition and rewards to openly acknowledge technical and administrative contributions to the organization at all levels. Such recognition would enhance the perception that management cares about how things are done, not just about what is done.

Division leadership should seek new ways to communicate to all staff, including that of involving all of the team as part of the project planning process. Gaining all of the staff's input and acceptance of program objectives, budget limitations, and milestones is the motivation. This can result in higher staff morale. The technical staff voiced concern that a disconnect exists between the information that management thinks it is sharing and the information that the technical staff receives and acts upon. Communication both up and down the ladder when budget reduction, performance enhancement, and direction are being questioned may help bring teams together for a win-win outcome.

Given the resource restraints under which the division has had to operate for the past few years, the staff and management have made great sacrifices to balance competing needs for operations, infrastructure improvements, and metrology development activities. Nearly every scientist is involved in SRM development and certification. The challenge for leadership is how to find the funds to grow or maintain essential technologies for the development of new SRMs, the division's key product. The impact of reduced resources (people, equipment, and funds) is taking a toll on the staff and on their ability to respond to a broader range of commercial SRM needs. The division should more often critically assess the opportunities to delete programs and SRMs so that greater emphasis can be placed on priority projects.

To continue to provide the state-of-the-art SRMs and metrology techniques required by U.S. industry, division staff must have access to modern analytical instrumentation comparable to that used by the laboratories of their industrial contemporaries. A more aggressive procurement plan for analytical instrumentation should be developed and implemented. Key to this plan would be a time line and a listing of alternative sources (e.g., customer cost-share) of funding for the purchase of instrumentation. The panel noted shortcomings in novel instrumentation developments or the use of the most modern commercially available instrumentation in many groups. The lack of collision-cell ICP-MS instrumentation and updated gas chromatographs are examples. The panel suggests that the division leadership act upon next-generation instrumentation needs for metrology research. Novel instrumentation beyond what is commercially available is needed for leading-edge problem solving in metrology.

5

Physics Laboratory

PANEL MEMBERS

Janet S. Fender, Air Force Research Laboratory, *Chair*
Duncan T. Moore, University of Rochester, *Vice Chair*
Patricia A. Baisden, Lawrence Livermore National Laboratory
Anthony J. Berejka, Consultant, Huntington, New York
John H. Bruning, Corning Tropel Corporation
John F. Dicello, Johns Hopkins University
Jay M. Eastman, Lucid, Inc.
Stephen D. Fantone, Optikos Corporation
Thomas F. Gallagher, University of Virginia
R. Michael Garvey, Datum Timing, Test and Measurement, Inc.
Lene Vestergaard Hau, Harvard University
Tony F. Heinz, Columbia University
Jan F. Herbst, General Motors Research and Development Center
Franz J. Himpsel, University of Wisconsin
David S. Leckrone, Goddard Space Flight Center, NASA
Dennis M. Mills, Argonne National Laboratory
James M. Palmer, University of Arizona
William N. Partlo, Cymer, Inc.
Thad G. Walker, University of Wisconsin-Madison
Frank W. Wise, Cornell University

Submitted for the panel by its Chair, Janet S. Fender, and its Vice Chair, Duncan T. Moore, this assessment of the fiscal year 2002 activities of the Physics Laboratory is based on site visits by individual panel members, a formal meeting of the panel on February 20-21, 2002, in Boulder, Colorado, and documents provided by the laboratory.[1]

[1]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Physics Laboratory: Technical Activities 2001,* NISTIR 6838, National Institute of Standards and Technology, Gaithersburg, Md., January 2002, and U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Physics Laboratory: Annual Report 2001*, National Institute of Standards and Technology, Gaithersburg, Md., January 2002.

LABORATORY-LEVEL REVIEW

Technical Merit

The Physics Laboratory states 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 (see Figure 5.1): Electron and Optical Physics Division, Atomic Physics Division, Optical Technology Division, Ionizing Radiation Division, Time and Frequency Division, and Quantum Physics Division (JILA). The first five divisions are reviewed below under Divisional Reviews; the Quantum Physics Division is reviewed as part of the subpanel report on JILA found at the end of this chapter.

The NIST Physics Laboratory has long been known among its technical peers for the outstanding level of scientific research that it produces. 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

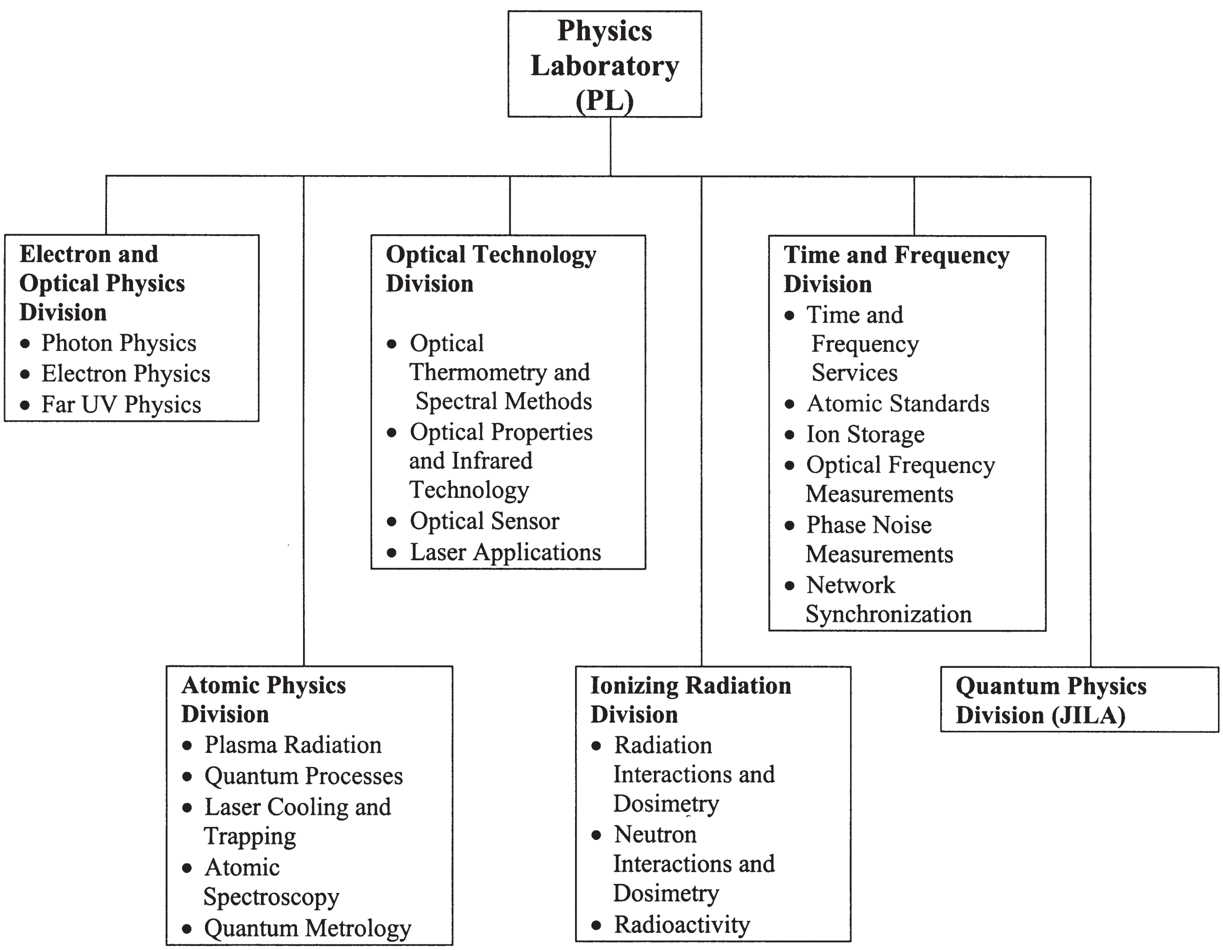

FIGURE 5.1 Organizational structure of the Physics Laboratory. Listed under each division except Quantum Physics (JILA) are the division's groups.

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 this technical tradition continues throughout the laboratory. The panel continues to be impressed with the quality and the quantity of top-notch scientific results that the laboratory produces. The awarding of the Nobel Prize for Physics to a laboratory researcher (Eric Cornell) for the second time in 5 years is the most obvious indicator of the quality of this work. Throughout the laboratory, researchers have an impressive record of publication in leading peer-reviewed scientific journals, of presentations at leading technical conferences, and of invited talks at leading conferences—three common measures of technical merit that are also indicative of the respect that NIST scientists and their work are accorded by their technical peers.

An outstanding technical accomplishment realized by the laboratory in the past year is the demonstration of a frequency standard that utilizes optical radiation rather than microwave radiation. Since optical frequency transitions have much higher precision than that of the microwave frequency transitions that are the basis of current standards and since these optical transitions can now be measured with the required accuracy, a primary frequency standard based on optical transitions with 1,000 times better precision than that of current standards should ultimately be enabled. This development can subsequently translate into similar improvements in measurements of time. Better measurements of time raise the possibility of increasing transmission rates in telecommunications applications, improving the security of military communications, and enhancing the capabilities of the Global Positioning System (GPS) and its applications.

Other examples of noteworthy technical achievements in the laboratory are presented in the divisional reviews below.

Program Relevance and Effectiveness

The panel has noticed an improving focus on the relevance of programs to customer needs in the Physics Laboratory. Areas that have traditionally had strong customer ties—such as standards and calibrations for optical applications and for applications of ionizing radiation—remain strong. A sharp focus on goals and customer needs has been apparent in the new effort to develop chip-scale atomic clocks. The health care initiative, which has been under development for several years, is evolving into a well-organized, cross-laboratory effort. Eight areas of focus in health care have been identified, based on need for standards and measurements and on existing NIST technical strengths. Significant outreach to potential customers in the medical physics community is ongoing.

The laboratory is to be particularly commended for its responsiveness to national need during the anthrax attacks of late 2001. Existing NIST expertise in the measurement of electron-beam dose was quickly mobilized to test the effectiveness of electron-beam decontamination of mail, which allowed the resumption of mail delivery to federal sites. NIST coordinated the interagency task force set up by the White House to address this situation. The dedication and expertise of NIST staff and the existing NIST infrastructure in this area enabled a rapid response to this unanticipated situation and resulted in a reliable decontamination procedure to meet the immediate need to get mail moving again. This technical team continues to work on refining the decontamination procedure to reduce damage to vulnerable mailed objects, such as magnetic recording media. The Physics Laboratory could capitalize on its spectacular success in this effort, and also help accomplish NIST aims in homeland security, by developing an aggressive proposal in this area with appropriate federal and private partnerships.

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 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.

The NIST Physics Laboratory generates significant new knowledge and technology, some of which may have commercial value. It is consistent with the mission of NIST to protect the technology it develops so that it can be used in a manner that best serves the national interests of the United States and its citizens, both individual and corporate. However, there is concern among panel members that NIST staff have only a rudimentary understanding of intellectual property (IP) issues and of methods for transferring NIST IP to U.S. industry. Furthermore, the Physics Laboratory leadership does not encourage the consideration of U.S. IP protection as a deliberate process. Without such deliberate consideration, IP that would contribute more to U.S. competitiveness if protected can fall into the public domain. The panel recommends that NIST management examine its IP policy and focus on clearly communicating that policy to technical staff at all levels so that IP protection is sought when it is appropriate to do so.

Laboratory Resources

Funding sources for the Physics Laboratory are shown in Table 5.1. As of January 2002, staffing for the Physics Laboratory included 196 full-time permanent positions, of which 161 were for technical professionals. There were also 55 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

It is difficult to assess the appropriateness of the current resource allocation within the laboratory because the panel has no indication of how the current allocation of resources was made relative to priorities, potential payoffs, and time horizons. An overall strategy for budget allocation was not presented to the panel, and it is not clear how relative funding decisions are made within the laboratory against overall strategic goals. An overall strategy for resources that accounts for core competencies that must be maintained and that is coordinated with priorities at the NIST level could help ensure continuity of funding for long-term projects and priorities.

The laboratory should evaluate options for the provision of measurement services such as calibrations, Standard Reference Materials, and databases. If mature technologies can be transitioned out of the laboratory (whether through commercialization, the National Voluntary Laboratory Accreditation Program [NVLAP], fee for service, industrial or university partnerships, or other mechanisms), it would

[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.

TABLE 5.1 Sources of Funding for the Physics Laboratory (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	33.0	33.0	34.0	35.9
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	13.5
Other Reimbursable	3.6	4.2	4.4	4.5
Total	50.4	51.6	55.6	58.5
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.

free NIST scientists involved in those services to spend more time on creative tasks and development of new technologies. The laboratory's successful establishment of secondary laboratories for medical standards and radiation measurements through the Accredited Dosimetry Calibration Laboratories (ADCLs) is a good example of achieving more optimal use of NIST resources through technology transfer.

Resource limitations call out for maximum leveraging of available resources, not only in cross-divisional work but also in cross-laboratory work within NIST. The panel was pleased to see that the health care initiative being championed by the laboratory is coordinating resources in this area across several NIST laboratories in a meaningful way. As the initiative continues, the panel hopes to see these interlaboratory relationships further nurtured and matured. The Physics Laboratory should continually be alert to other areas in which interlaboratory cooperation can stretch its own resources and provide for results of greatest customer impact.

The panel encourages the Physics Laboratory to take a leadership role in developing consortia and partnerships to address national issues. In addition to fulfilling the mission of NIST, such efforts will raise the public's and the government's awareness of the value of NIST. Such activities could leverage industry and public dollars and boost the NIST budget as decision makers perceive the organization to be of high value to the nation.

Several division managers were concerned that rising NIST overhead rates are consuming greater percentages of their budgets. Data indicates that the overhead rate has risen from 44 percent in 1997 to 54 percent in 2002. Without a detailed review of what the overhead rate supports and what base it is charged against, the panel cannot determine if this rate is inappropriate. However, the panel is concerned about the impact it has on the resources available for technical programs. The overhead rate might merit review by the NIST director.

Laboratory Responsiveness

The primary recommendation made by the panel in its previous report was to improve the focus of programs through clearly articulated, overall strategic goals for the Physics Laboratory. As noted above, the laboratory took the first step toward responding to this recommendation. Much work remains to be done in order to produce the coherent, well-understood strategy for the laboratory that is necessary to achieve the program focus and coordination that the panel envisions. As this is clearly not a 1-year process and must emanate from the divisions, the panel looks forward to continued progress on this topic.

Last year, when presented with a Physics Laboratory initiative in biophysics, the panel remarked that the initiative, as presented, lacked focus and did not have an obvious role for Physics Laboratory competencies. Since that time, the initiative has been refocused into the area of health care, and has been developed into a NIST-wide Strategic Focus Area (SFA). While much of the planning and prioritizing that went into this new health care SFA occurred at a level higher than the Physics Laboratory, the laboratory is to be commended for the active role it played in its development and for the leadership that it is showing in the organization and management of the interlaboratory effort.

In last year's assessment, the panel also recommended clearer program goals for the laboratory in the area of nanotechnology. Nanotechnology has now been raised to the level of a NIST-wide initiative, and the Physics Laboratory program has benefited from the increased focus and strategy that planning on the NIST level is bringing to work in this area. Furthermore, the Physics Laboratory has engaged in numerous nationally sponsored nanotechnology activities to firmly establish the leadership role of NIST in this important emerging area. At this time, a clear definition of specific Physics Laboratory goals in nanotechnology would help assure the best application of resources in this area.

The panel was particularly impressed with the responsiveness of the Atomic Physics Division to last year's report and recommendations. In response to panel concerns about the relevance of work in Gaseous Electronics Conference (GEC) reference cells, the division examined its program in that area, determined an appropriate focus for research, and redirected its efforts accordingly. The panel was impressed with how quickly and effectively the division was able to make changes in order to allocate its resources in this area more effectively.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- The Physics Laboratory continues its tradition of technical excellence and leadership. The awarding of the 2001 Nobel Prize in Physics to one of the laboratory's staff members is the most obvious evidence of this excellence.
- The Physics Laboratory reaction to the anthrax attacks of late 2001 was outstanding for its responsiveness to unanticipated national need and for its excellent utilization of established NIST skills and resources. Staff involved in this effort are deserving of the highest praise and gratitude.

- The panel commends the leadership role that the Physics Laboratory is taking in the NIST-wide health care initiative and the strong focus that the laboratory has brought to its efforts in this area in the past year.
- 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 by the laboratory and its divisions to allocate resources, determine program prioritization, and produce enhanced program focus and effectiveness.
- The panel recommends enhanced efforts to develop interlaboratory collaborations and other partnerships that would help leverage Physics Laboratory resources while more effectively meeting NIST-wide strategic goals.

DIVISIONAL REVIEWS

Electron and Optical Physics Division

Technical Merit

The Electron and Optical Physics Division's mission is to support the NIST mission by developing the measurement capabilities needed by emerging electronic and optical technologies, particularly those required for submicrometer fabrication and analysis. The division is composed of three groups: Photon Physics, Electron Physics, and Far UV Physics.

Photon Physics. The principal focus of the Photon Physics Group is the creation and characterization of metrology tools and methods in the spectral region of extreme ultraviolet (EUV) radiation. This spectral region is of considerable importance and relevance owing to the development of EUV lithography, which is the strongest candidate to follow deep ultraviolet (DUV) lithography, currently used in volume production of integrated circuits (IC). The availability of production-ready EUV lithographic tools at the end of this decade will be critical for maintaining U.S. competitiveness in the field of advanced IC fabrication.

The group's Synchrotron Ultraviolet Radiation Facility (SURF III) is an EUV radiation source that can be selected for the wavelength regions relevant to lithography, principally centered at 13.5 nm and 157 nm. Extensive work has been done over the past year on the RF drive electronics used to maintain electron energy inside the SURF's storage ring. SURF III has several radiation ports dedicated for use in the characterization of EUV detectors and mirrors. The reliable EUV output provided by SURF III and the dedication of several radiation ports for EUV work provides a significant measurement capability.

Last year the Photon Physics Group completed the large-sample EUV reflectometry facility. This is one of the few facilities in the world able to characterize the large (up to 40-cm diameter) EUV mirrors needed by industry for full-field lithographic exposure tools. The Photon Physics Group is one of five participants worldwide in a round-robin measurement testing exercise in the characterization of EUV mirrors. Five different mirrors, each produced by a separate laboratory, have been measured by each facility; comparison results were presented in March 2002 at the Society for Photo-Optical Instrumentation Engineers (SPIE) microlithography conference.

At the present time, a very limited commercial EUV detector infrastructure exists, and no commercial calibration services are available for EUV detectors. The Photon Physics Group's ability to characterize and calibrate EUV detectors is an important factor in the growth of this technology. In addition, this group is uniquely positioned to investigate a fundamental assumption made by nearly all users of calibrated EUV photodiodes. These EUV photodiodes are calibrated with quasi-continuous wave (CW) synchrotron radiation sources but are then used to measure the output from pulsed EUV light sources. The calibration is assumed to be consistent between CW and pulsed operation of these photodiodes. The Photon Physics Group has constructed a pulsed EUV radiation source based on the gas jet laser-produced plasma concept, and it plans to compare calibration with this pulsed source to that made with the quasi-CW output from SURF III.

Many research organizations around the world are developing EUV light sources, each following quite a different technological path. Consistent measurement of source parameters such as average in-band emission, in-band emission stability, out-of-band emission, source size, source position stability, and debris generation is critical when making comparisons among EUV source suppliers. The expertise of the Photon Physics Group and the reputation of NIST make it ideally suited for creating this suite of tests. It is recommended that the Photon Physics Group approach EUV source vendors and EUV exposure tool suppliers and ascertain the level of interest in providing this function to the EUV technical community.

Because of the clean, debris-free output and extended continuous operation capability of SURF III, the Photon Physics Group is well positioned to contribute to important studies of EUV mirror lifetime and degradation mechanisms. To date, industry emphasis has been placed on developing strategies directed toward mitigation of mirror damage caused by contaminants such as carbon and oxygen. Little is known about possible degradation of the dielectric coatings under long-term exposure to EUV radiation. The clean, high-vacuum environment afforded by a synchrotron radiation source such as SURF III is essential for achieving long-term EUV exposures free from contaminants. The division should consider pursuing funding for such work.

Electron Physics. The Electron Physics Group pioneers the development of world-class measurement techniques and uses them to confront challenging problems at the nanoscience frontier. Last year the panel reported on the completion of the Nanoscale Physics Laboratory (NPL), a scanning tunneling microscope (STM) coupled to two molecular beam epitaxy (MBE) systems and a field ion microscope unit for tip preparation. A fixed-direction magnetic field as large as 10 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 facility positions the group to remain a leader in the preparation and characterization of nanostructured materials well into the future. Recent improvements in the system's electronics have made it possible to resolve meV features. A fascinating study currently under way on this system employs the spin-dependent STM capability to enable spectroscopic investigation of energy gap states in superconducting V_3Si films grown in situ. NIST has observed magnetic tunneling effects on the subnanometer scale that do not fit conventional models. This discovery of new physics is a good indication that the experiments probe uncharted territory. Testing of atom manipulation has also begun, as part of the larger goal of developing an autonomous atom assembler that will afford atom-by-atom fabrication of quantum structures.

Single-atom manipulation is also the objective of the "atom on demand" work, which relies on capturing an individual atom in a magneto-optical trap and moving it with lasers. Potential applications include building an atomic array for quantum information processing and modulated doping of a substrate. The essential step of counting the number of atoms in the trap was accomplished in 2001 by detecting their fluorescence. This project dovetails very well with the quantum computing effort at Boulder and gives NIST an edge in this very competitive field.

The Scanning Electron Microscopy with Polarization Analysis (SEMPA) project was enhanced with the installation of an ultrahigh vacuum, field emission scanning electron microscope during 2000-2001. This instrument is now functioning at a magnetic image resolution of 25 nm, with an ultimate goal of achieving 10-nm resolution. A critical need exists for mapping the magnetic domain structure on that scale because it is characteristic of magnetic storage media for hard disks. Owing to vendor delays in meeting specifications, the instrument has not quite reached 10-nm resolution, but it is already better than the available magnetic microscopes, such as other SEMPA instruments, the MFM (magnetic force microscope), and the PEEM (photoemission electron microscope) with magnetic circular dichroism. Measurements can be made in the 100 to 1000 K temperature range, and structures such as multilayer wedges can be grown by MBE and characterized with techniques including reflection high-energy electron diffraction. Two recent SEMPA efforts are very exciting. First, magnetization directions of magnetic nanostructures in patterned thin films were imaged directly. The structures are Fe and Co disks and rings several nanometers thick and 1 to 10 mm in diameter that have potential application in nonvolatile magnetic memories. Second, electron-beam-induced magnetic switching has been observed in epitaxial Fe (110) films grown on a GaAs (110) surface.

A high-risk effort is under way to achieve atomic-scale magnetic contrast in a separate, room-temperature STM. One set of experiments is designed to monitor the circular polarization of light generated by tunneling from a ferromagnetic sample into a p-doped GaAs tip. If this technique is viable, several impediments to obtaining magnetic contrast using magnetic tips will be eliminated, including undesirable tip-sample interactions, unknown orientation of the tip magnetization, and lack of distinction between magnetization and topographic images. Novel work on magnetic tips is being pursued in parallel. This group's pioneering work on spin-polarized electron emission from GaAs photocathodes (the reverse of the process investigated by STM) is the most frequently cited paper in *Review of Scientific Instruments* over the last 30 years.

A talented and creative theoretical component complements the experimental effort. Interacting with researchers within as well as outside NIST, the theorists generate ideas for experiments and provide an additional resource for problem solving. One theorist works in a highly collaborative manner; for example, NIST experimentalists, a NIST theorist, and scientists from the Naval Research Laboratory (NRL), IBM, and Oxford and Cambridge Universities collaborated on spin polarization in STM. Among recent theoretical activities are an investigation of noncollinear spin transfer in Co/Cu/Co multilayers and work on the impact of spin-other-orbit interactions on the magnetocrystalline anisotropy energy of the 3d transition metals.

Far UV Physics. The Far UV Physics Group operates and continually improves SURF III. A newly installed near-UV Fourier transform interferometer will provide high-precision optical constants for the next-generation (157-nm) optical lithography. An upgrade of the RF system is under way to allow better control of the third harmonic of the resulting radiation beam, which will make it possible to control instabilities at low beam energies, resulting in more precise measurements for SURF III users.

As pointed out in the previous assessment report, opportunities exist for exploiting the unique capabilities of SURF III in producing spectrally pure and easily tunable photons in the 3- to 6-eV energy regime, which covers the range of work functions. One option would be to install a photoelectron microscope that uses work function differences for producing contrast. Near threshold, the chromatic aberrations are negligible that affect the resolution at the higher energies used by other synchrotron light sources. Infrared spectroscopy and microscopy will benefit from the improved beam stability. The group should consider the possibility of exploiting these capabilities.

Program Relevance and Effectiveness

Many organizations are in crucial need of the capabilities and knowledge base of the Electron and Optical Physics Division. Among the customers of the Photon Physics and Far UV Physics Groups are companies and agencies that need calibration standards for radiometry such as calibrated photodiodes, calibrated charge-coupled detectors for solar activity (Naval Research Laboratory), and transmission gratings for space astronomy. One large customer is the EUV Limited Liability Corporation (LLC) consortium, whose members include Intel, Motorola, Advanced Micro Devices (AMD), Lawrence Livermore National Laboratory (LLNL), and Lawrence Berkeley National Laboratory (LBNL). Major objectives of the consortium are quantitative assessment of radiation damage and lifetime of EUV optics, determination of optical constants, and reflectivity measurements for mirrors.

The pioneering research activities of the Electron Physics Group in nanoscale science and technology ensure the work's relevance to a wide spectrum of customers across industry, academia, and government. For example, the SEMPA capability for high-resolution magnetic imaging has spawned current collaborations with Seagate; IBM; MIT; Cambridge University; the Johns Hopkins University; the University of California, San Diego; the University of Utah; and NRL. Given its promise for fabricating nanostructures atom by atom and for measuring their electronic and magnetic properties, the Nanoscale Physics Laboratory is likely to generate customer interest on a number of fronts—among them, atom manipulation for device structures, the study of the intrinsic physics of atom-solid interactions, and quantum computing. As indicated above, quantum information processing and modulated doping are also potential application arenas for the "atom on demand" effort.

Results of division research are shared with customers by many different means, including direct communications, presentations at technical meetings, and reports. The substantial number of high-quality papers by division researchers in the refereed scientific literature is especially noteworthy. The panel expects that the division will maintain this level of presence in the external technical community.

Division Resources

Funding sources for the Electron and Optical Physics Division are shown in Table 5.2. As of January 2002, staffing for the division included 23 full-time permanent positions, of which 20 were for

TABLE 5.2 Sources of Funding for the Electron and Optical Physics Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.0	5.4	5.5	5.5
Competence	0.0	0.0	0.2	0.2
ATP	0.2	0.1	0.2	0.1
OA/NFG/CRADA	0.6	0.5	0.8	1.2
Other Reimbursable	0.1	0.1	0.0	0.0
Total	5.9	6.1	6.7	7.0
Full-time permanent staff (total)[a]	23	23	24	23

NOTE: Sources of funding are as described in the note accompanying Table 5.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

technical professionals. There were also 9 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Funding for the division is adequate, although maintaining it requires persistent struggle. It appears that projects that successfully attract funding are frequently "taxed" to fund new initiatives. Division staff also reported a large increase in overhead charges during the past 2 years.

Morale is excellent. In general, the members of the division greatly enjoy the intellectual stimulation and excitement of working on very interesting projects with talented colleagues. The fact that NIST scientists have received two Nobel prizes over the past 5 years is in no small part responsible for the high level of enthusiasm.

Atomic Physics Division

Technical Merit

The mission of the Atomic Physics Division is to carry out a broad range of experimental and theoretical research in support of emerging technologies, industrial needs, and national science programs. It is organized in five groups: Plasma Radiation, Quantum Processes, Laser Cooling and Trapping, Atomic Spectroscopy, and Quantum Metrology.

Plasma Radiation. The Plasma Radiation Group operates the laboratory's electron-beam ion trap (EBIT), a unique, well-characterized facility that allows fundamental studies of a variety of processes with highly charged ions for both fundamental science and applications. Through the use of EBIT, the division continues to be a leader in studies of fundamental properties of highly charged ions. This well-instrumented, well-characterized facility allows the division to make unique and important contributions on a wide variety of topics. Most recently, a new cutting-edge space-compatible microcalorimeter allowed the group to make a number of studies of astrophysical significance.

Over the past several years, this group has been exploring the application of highly charged ions for surface modification and processing. After an initial exploratory procedure, the group has focused its efforts on using ions for the production of nanostructures on the surfaces of silicon and silicon dioxide, with potential applications in microelectronics and biotechnology. The division developed expertise in the imaging of this surface, and it seems that this activity could be poised to produce some significant results in the next 12 to 18 months.

The Plasma Radiation Group is successfully pursuing optical measurements of the properties of optical materials at the 157-nm wavelength so important to future-generation lithography for integrated circuits. The group discovered intrinsic birefringence 10 times the design limits for the key materials CaF_2 and BaF_2 and is currently working on solving this intrinsic birefringence problem.

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 plays an important leadership role in the theoretical AMO community in the United States. The group provides important theoretical support for a variety of experimental efforts in atomic clocks, quantum degenerate gases, quantum dots, single-molecule detection, and quantum information. The group is distinguished by its emphasis on realistic models of the processes under study, and for this reason it is often able to confront experiments in meaningful ways. Over the years, this group has developed a number of numerical codes and applied them successfully to a wide variety of physical, chemical, and optical phenomena. It is also playing an important leadership role in the NIST Quantum Information initiative.

Over the past year, the Quantum Processes Group has made a number of significant advances. It has developed and is continuing to develop methods for theoretically analyzing the collisional properties of atoms confined in optical lattices, in particular, simulating the process of generating entanglement. It has advanced a strikingly successful theory of the complex collisional behaviors of ultracold Cs atoms. It has advanced the art of simulation of quantum dots. Its simulations of nanoscale optics have led to key new insights into the interpretation of near-field scanning microscopy images. The group continues to interact strongly and fruitfully with the Laser Cooling and Trapping Group and with other NIST scientists outside the Atomic Physics Division.

Laser Cooling and Trapping. Extremely active, productive, and visible, the Laser Cooling and Trapping Group is one of the world's leading groups in the field of cold atoms and Bose-Einstein condensation. The level of interaction between senior scientists is extremely healthy and is attracting many first-rate postdoctoral fellows.

The unusually fruitful collaboration between the experimentalists in this group and the theorists in the Quantum Processes Group is noteworthy. The theorists have immediate access to new experimental data, and that leads to meaningful theory rather than to a toy model approach with minimal relevance to the real world. The interaction creates a synergy in which the experimenters and theorists share the lead to new developments.

Atomic Spectroscopy. The Atomic Spectroscopy Group plays a prominent and visible role in providing essential support for the national scientific and industrial infrastructure, in the form of critical evaluations of the fundamental constants and atomic data. The group is aggressively pursuing a dramatic shortening of the time between comprehensive fundamental constants updates—from 13 years to 4 years. The accelerated process is enabled by a new, Tex-based data entry system, allowing real-time entry and proofreading. The Atomic Data Center provides critically evaluated data on atomic spectroscopy, a service of tremendous value, as evidenced by the roughly 1 million hits per year on its Web site by commercial, academic, governmental, and international users.

Quantum Metrology. The Quantum Metrology Group works primarily in the use of x-rays and gamma-rays for wavelength standards, materials optical properties, and determination of binding energies through the use of gamma-ray spectroscopy, and other precision measurements. Closely coupled to these areas is a program on atomic displacement metrology for achieving a better understanding of errors in interferometric measurements so that these techniques may be extended in their range and accuracy (which is related to the x-ray work of the group through x-ray interferometry). These activities are world-class in caliber and clearly support a core function of NIST. In addition, work is ongoing to investigate issues in high-resolution x-ray diffraction and reflectometry, particularly as applied to semiconductor-related problems and biological materials. Although these programs are relatively new and have not gained the international status of the group's other programs, they are technically sound and also relate to a core function of NIST. This group also provides its expertise in x-ray optical systems to the U.S. inertial fusion program by designing a diagnostic module for the NRL to be delivered to the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory.

Program Relevance and Effectiveness

The panel commends the Atomic Physics Division for clearly and coherently responding to issues raised by previous panel reports.

The EBIT team has established a productive relationship with astrophysicists at Harvard University supporting present and future orbiting x-ray instruments—Chandra, X-ray Multi-Mirror (XMM), and Constellation X. The Harvard group is currently developing a dedicated instrument to mount on the EBIT.

It is imperative that the EBIT surface team continue to interact closely with academic and industrial collaborators to ensure both that their new techniques are unique and that they address current microelectronics and biotechnology needs.

In response to panel concerns, GEC reference cell work is now focusing on submillimeter absorption spectroscopy diagnostics for plasma processing. Two companies, Air Products and Lam Research, are actively interested in collaborations with NIST for the use of this work for diagnostics of commercial etching reactors. Although the NIST GEC cell is not unique, the applications of the cell at NIST appear to be unique and of demonstrable utility in an important commercial sector.

Work on the optical properties of CaF_2 and BaF_2 at 157-nm and shorter wavelengths provides important information to designers of optical systems for 157-nm lithography and has already had an impact on the designs of some lens systems for next-generation lithography. This work is well aligned with one of the laboratory's Strategic Focus Areas—optics—and these measurements appear to be unique in the world. The concept of developing $Ca_{1-x}Ba_xF_2$ compounds to mitigate the effects of birefringence is clearly worth pursuing. The group needs to remain "ahead of the game" in order to be prepared for future generations of UV lithography systems.

As one of the very few AMO theory groups in the country, the Quantum Processes Group plays a vital role in supporting experimental efforts across the nation. The group's efforts in supporting fundamental and applied AMO science overlap strongly with the NIST core measurement and metrology functions. For example, its theoretical work in quantum information will directly support advances in quantum measurements of great importance to standards.

The Atomic Spectroscopy Group's evaluations of fundamental constants are also central and vital to the NIST core mission.

Work on critical evaluation and compilation of atomic data remains vibrant. The online data archive has addressed every problem raised in user feedback, and important new spectra have been added relevant to fusion research, microlithography, commercial lighting, and astrophysics. The Web-based data archive (physics.nist.gov/cgi-bin/AtData/main_asd) continues to enjoy more than 70,000 hits per month. Of particular note is a new Web-based archive of spectral data needed for the interpretation of x-ray observations obtained by the orbiting Chandra observatory. A potentially very useful new product, a handbook of the most commonly used spectroscopic data for neutral and singly ionized atoms of 99 elements, will be available in printed form and electronically later in 2002.

The division has a new CRADA in support of the lighting industry, involving a consortium of Phillips, General Electric, the University of Wisconsin, the University of Illinois, Los Alamos National Laboratory (LANL), NIST, and the Electric Power Research Institute (EPRI). One important objective of this work is improvement of the efficiency of plasma light sources used throughout the United States. Currently there are about 1 billion such sources, consuming roughly 100 GW of electric power annually. Even a 10 percent improvement in power consumption efficiency would translate into energy savings equivalent to production from multiple large power plants.

A connection between NIST and industry is being developed under the Consortium for High-resolution X-ray Calibration Strategies. This effort is to be commended, and similar collaborations should be sought in the area of x-ray activities related to biological systems to ensure that the division's proposed work is relevant. Similar consortiums or collaborations might also be considered between NIST and the third-generation x-ray synchrotron sources, which pursue topics similar to those being

TABLE 5.3 Sources of Funding for the Atomic Physics Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	6.7	6.8	7.3	7.0
Competence	0.3	0.3	0.7	0.5
ATP	0.2	0.3	0.3	0.4
OA/NFG/CRADA	0.8	1.1	1.7	1.5
Other Reimbursable	0.2	0.1	0.0	0.1
Total	8.2	8.6	10.0	9.5
Full-time permanent staff (total)[a]	32	31	35	34

NOTE: Sources of funding are as described in the note accompanying Table 5.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

addressed at NIST (high-precision angle measurement; comparison of surface roughness measurements using visible light, x-rays, and atomic force microscopy; and so on).

Division Resources

Funding sources for the Atomic Physics Division are shown in Table 5.3. As of January 2002, staffing for the division included 34 full-time permanent positions, of which 26 were for technical professionals. There were also 11 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The division is concerned about steadily increasing overhead rates. The panel perceives significant increases in NIST-wide administrative loads—both financially (overhead) and in terms of the amounts of time required of division personnel. Funding for this division has been effectively decreasing for several years, and the panel is concerned for its long-term financial health.

In order to meet its computing needs, the division is currently maintaining its own computer networks using permanent scientific staff, while paying for NIST-wide services via overhead. This is a burden on key staff talent. The division should investigate other means to meet its networking needs.

Given the attrition of an aging staff, the long-term future of the Atomic Spectroscopy Group has been one of the major concerns of the panel over the past 3 years. Laboratory management was strongly committed to shoring up this area by devoting significant funding to underwrite a 7-year plan to acquire first-rate young talent and to foster the mentoring of the new people by senior staff. This 7-year initiative has now been prematurely terminated. The loss of this funding has been offset by new funding freed up as a result of a retirement, so there is no immediate problem with funding. However, this is likely a short-term fix. The hiring of new staff members in this area has gone slowly and has suffered several setbacks—ever-increasing overhead rates and salaries that must be absorbed within a fixed pool of salary money, and loss of funding support from NASA. The NIST atomic database is unique in the world. Most other such databases rely on the NIST database as their primary source for critically evaluated atomic data. There will be a major ripple effect if the NIST database work is abandoned in the future. The panel would strongly disagree with any NIST decision to abandon its long-standing commitment to provide this critical resource to the national and international scientific, defense, and commercial sectors.

Currently, the Quantum Metrology Group consists of only four permanent staff members. This past year the group's long-time leader passed away, leaving a void in the group's vision and prioritizing. It is difficult to see how the group can continue all of its programs and complete them in a timely manner, given the limited number of personnel available. Under flat budgets, difficult decisions will have to be made to postpone or curtail some programs; otherwise, all programs will suffer. Without additional resources and manpower, insufficient funding will be available to adequately support the group's current, wide-ranging activities.

Optical Technology Division

Technical Merit

The Optical Technology Division's stated mission within NIST is to advance knowledge; to develop expertise; to provide technical leadership; and to deliver 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 (VUV). The division's goals in their totality are unique within the U.S. science and technology infrastructure, as are the division's current capabilities to meet them. The division is organized in four groups: Optical Thermometry and Spectral Methods, Optical Properties and Infrared Technology, Optical Sensor, and Laser Applications. For this division, organization by groups is largely administrative, as productive interaction among individuals, groups, and other NIST laboratories is an avowed goal of division management. Consequently, the assessment presented below is not organized explicitly by group but aims to provide an integrated discussion of the activities of the division.

The activities of the Optical Technology Division are diverse, encompassing areas from basic research on light-matter interactions, to applications of light scattering as a metrological tool for the characterization of solid surfaces, to sustained interactions with scientists and engineers in establishing methodologies and standards for industries relying on optical technologies. The division has targeted research programs to develop optical and spectroscopic tools for gathering information on processes in the frequency ranges required to support evolving technologies in the semiconductor, biotechnology, health science, and other industries. The research also aims to solve fundamental problems in the physics, chemistry, and engineering science that underlie these applications. The Optical Technology Division also 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. These measurement responsibilities include derived photometric and radiometric units, the radiance temperature scale, spectral source and detector scales, and optical properties of materials, such as reflectance and transmittance.

The Optical Technology Division is involved in the development and application of new methods to make the far-infrared and submillimeter-wave spectral regions more accessible. This effort is part of a broader, laboratorywide competence initiative in terahertz measurements. The program aims to extend and improve capabilities for optical measurements in the far-infrared, traditionally one of the most inaccessible portions of the electromagnetic spectrum, but one of great spectroscopic importance for many disciplines and technologies. Several distinct approaches are being pursued within the division. One of these relies on CW terahertz techniques, including photomixing with tunable visible lasers. Another relies on unique, high-performance electron devices. A complementary set of techniques exploits the capabilities of ultrafast pulsed lasers. In this scheme, ultrafast electromagnetic transients are produced from laser pulses by photoconductivity or optical rectification. The electromagnetic transients are characterized directly in the time domain by sampling techniques using a copy of the ultrafast laser pulse that produced them. These diverse investigations in their totality clearly place NIST at the forefront of an extremely vital and rapidly evolving active technical area. They build on the division's traditional strength in infrared spectroscopy, including novel, multichannel detection schemes. In addition to establishing these new spectroscopic capabilities, the effort has led to unique measurements of physical and chemical systems with high scientific impact and implications for plasma processing, biotechnology, and other areas of national priority.

Another current frontier in optical spectroscopy concerns the analysis of small structures. This capability may apply to probing thin films, surface layers, organic and inorganic nanostructures, and single molecules—all structures of great scientific and technological importance. The division is carrying out research to develop or adapt spectroscopic techniques to examine material of reduced spatial dimensions and to perform unique scientific measurements using these capabilities. These activities are well aligned with other major initiatives in NIST and with areas of external importance, such as biotechnology, nanotechnology, photonics, and electronics. One component of the research program emphasizes precision measurements of surfaces and interfaces. The broadband, infrared-visible sum-frequency generation spectroscopy pioneered in the division combines the power of an interface-specific optical technique with the capability for rapid data collection of vibrational spectra. The division team has demonstrated the power of this approach in polymer interfaces and other material systems. This new research builds on the division's established expertise in the precise analysis of optical scattering and from its unique instrumentation. The program has elucidated fundamental issues and has been tightly coupled to materials characterization in the semiconductor industry. Results are being disseminated to customers through publicly available software for scattering analysis that can be downloaded from the NIST Web site.

A current initiative for spectroscopy of small structures concerns the extreme limit of single-molecule detection. Leading-edge work in developing the necessary tools and techniques for such measurements and their applications to biological problems are being vigorously pursued. This project builds on the expertise developed in the Optical Technology Division in the application of confocal and near-field microscopy to biological and biomimetic systems. The division has recently placed emphasis on the extension of fluorescence resonant energy transfer techniques to the single-molecule level for determination of distances on the nanometer scale. These investigations, supported by NIST competence funding for single-molecule measurement and manipulation, have the potential for significant impact in biophysics and biotechnology.

Radiometry, photometry, and spectrophotometry remain central to the division. This area has very close coupling to industry, and new innovations and requirements in diverse sectors drive new scientific and standards development. For example, new applications of light-emitting diodes (LEDs) for illumination and displays have stimulated considerable innovation in metrology and standards for photometry and colorimetry. The division has done an impressive job of evolving and adapting its tools and standards to address these technology changes. A truly innovative effort to improve the accuracy of laser photometry and the calibration of transfer standards is the High Accuracy Cryogenic Radiometer (HACR 2) Program. When complete, this instrument should provide a combined relative uncertainty of <0.01 percent, the best in the world.

The division's Facility for Automatic Spectroradiometric Calibrations (FASCAL) provides the basis for spectral irradiance and radiance measurements for U.S. industry, the scientific community, and the military. This facility is currently being upgraded to a second-generation instrument, FASCAL 2, which will improve the quality of calibration and the throughput. Both improvements are of significant benefit to users and are a direct response to long-expressed customer needs. FASCAL 2 will define best-in-the-world for the calibration of spectral irradiance sources. The FASCAL 2 system was designed to enable the transfer of the NIST spectral irradiance detector scale to sources used by NIST customers. In the past year, this chain of realization was actually implemented with the current FASCAL. Very significant reductions in uncertainty are now realized on all calibrations, but particularly in the near-infrared. The planned comparison of radiance and irradiance scales to establish the basic equivalence of their methods of realization and to estimate the importance of any experimental bias will further establish the certainty of the NIST realizations. The panel commends the division for having committed personnel, space, instrumentation funds, and other resources to the FASCAL upgrade project.

Optical technology plays a key role in the semiconductor industry, and NIST provides support through standards and optical characterization of materials. Over the past years, very rapid progress in photolithography has been achieved by moving quickly to shorter wavelengths—from mercury lamp-based illumination to 248-nm and more recently 193-nm pulsed excimer laser illumination sources. Many of the laboratory's programs are relevant to current photolithography, particularly those related to calibration, damage resistance, and stability of detectors at 193 nm and 157 nm. This relevance is becoming more important as illumination sources increase in average power, peak power, and repetition rate where detector nonlinearities, durability, and reliability become more questionable. The division's SURF III is unique and will enable critical metrology for the industrialization of DUV and VUV photolithography. This work should be accelerated, however, to match the time lines of the semiconductor industry.

Program Relevance and Effectiveness

The Optical Technology Division has a broad and significant mandate to address with limited resources. To this end, the division aims to focus on high-potential and high-impact activities at a level sufficient to maintain and enhance the global position of the United States in the relevant areas of science and technology. The panel's overall assessment is that the division is doing an outstanding job in choosing technical directions, in developing outside interactions, and in maintaining and upgrading facilities to ensure the highest degree of program relevance and effectiveness.

In carrying out the programs of the Optical Technology Division, there is constant need to evaluate and reevaluate priorities. The division mission encompasses needs that are changing rapidly, driven by the evolution of new technologies and by the need for improved metrology for existing technologies. This requires a dynamic program and also provides the impetus for the division's efforts in basic, long-term theoretical and experimental research. In this sense, the division's mission follows the two themes of the Physics Laboratory's mission: physics applied to support emerging technologies and physics applied to developing advanced measurement standards. The panel believes that a very suitable planning and management structure is in place to ensure program relevance and effectiveness. The division benefits from the inclusive, dynamic strategic planning approach implemented some years ago, as well as from broader discussions on the level of the Physics Laboratory and strategic planning for NIST. The division's effectiveness and relevance are enhanced by strong interactions with other divisions within NIST and with other government, industrial, and academic laboratories.

A central aspect of the division's priority setting involves interactions with 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. The division could further enhance the effectiveness of CORM by ensuring the broadest representation on and participation in CORM by the biomedical community. Also, as a procedural matter, CORM members are currently polled on their priorities before the issuance of the NIST response to the previous CORM report; the new CORM report essentially coincides with the NIST response to the old report. A mutual agreement should be sought between NIST and CORM whereby NIST produces its response at a fixed time (2 to 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 might then be initiated. The division has also maintained a dialogue with the UV Measurements Focus Group of the industrial association RadTech International North America. The division participates in the focus group's meetings and advises on its activities. The leadership of this focus group is now also involved in CORM.

The effectiveness and relevance of the division's projects may be gauged by the strong interactions of the division with industrial, government, and academic colleagues and customers and the level of support for ongoing projects from other government agencies, industry, and the ATP program. By this measure, the division's programs are very highly valued. The division's effectiveness and relevance are also reflected in its record of publications and presentations. Given the relatively small size of the effort, both the numbers and their scientific impact are excellent, a result attributable to both the quality of the researchers and their aggressive pursuit of new scientific directions. Adopting new directions has often required phasing out well-established directions that have significant but diminished scientific and technological relevance. Such steps are generally difficult and painful; the panel commends the division for taking such decisions.

The panel cites below a few examples of recent activities whose relevance and effectiveness are particularly high.

Especially noteworthy are the division's characterization and theoretical understanding of the phenomenon of intrinsic birefringence in transparent materials of cubic symmetry in the VUV spectral region. The existence of a measurable effect of this sort, seen in CaF_2 and other fluoride crystals, came as a surprise to optical scientists and engineers. Given the crucial role of such materials in current lithography technology, the effect is now recognized as very significant. The NIST studies explained this phenomenon theoretically and validated the models by measurement. This is world-class work and an important contribution to the photolithography community; it has revealed an important and unexpected optical materials issue in next-generation lithography.

Division work in optical scattering metrology has led to the development of a valuable set of software tools (SCATMECH) for a large class of materials and surfaces. This capability is very relevant for the semiconductor industry and other industrial applications in which process control and process yield require in-depth analysis of subtle surface and subsurface characteristics. The validity of these software tools has been extensively evaluated through laboratory experiments. The software is readily available at a user-friendly Web site (http://www.physics.nist.gov/Divisions/Div844/facilities/scatmech/html/index.htm) and has attracted considerable attention.

In response to pressing national needs, the division has undertaken measurements to assess the viability of spectroscopic detection of biological toxins in sealed envelopes using far-infrared spectroscopy. The rapid action of the division will permit a determination about the suitability and possibility range of application of this noninvasive measurement technique.

Radiometric calibrations of remote sensing satellites and other problems related to environmental monitoring pose new calibration challenges for field instruments. To answer these needs, the Optical Technology Division is developing a new portable instrument, dubbed the Traveling SIRCUS (spectral irradiance and radiance calibration with uniform sources) that will provide a broadly tunable, calibrated laser-based uniform source. Analogous to the SIRCUS instrument currently available at NIST, it will permit the highest-accuracy spectroradiometric calibrations to be performed at remote locations. This represents a significant extension of calibration capabilities in response to user demand.

The production of Standard Reference Materials (SRMs) is a key service offered by the division and used by many customers. SRMs produced include specular and diffuse reflectance and transmittance artifacts, and an infrared wavelength standard. The division also has the capability to make gloss measurements in accordance with the ASTM D253 and ISO 2813 standards. The division hopes soon to add reflective colorimetry and haze measurements to its list of services. The sixth and seventh CORM reports, *Pressing Problems* and *Projected National Needs in Optical Radiation Measurements* (www.corm.org/publicat.htm), request more SRMs in numerous areas. The Optical Technology Division plans to offer more calibration services as outlined in SP-250, with faster response, lower cost, and more direct communication between the division and the end user. This effort will also effectively address customer needs that are not being strictly met by existing SRMs.

International key intercomparisons of standards are critical to gathering the information needed to advise U.S. industry on metrology issues worldwide, to providing technical guidance on international memoranda of understanding affecting the U.S. economy, and to advancing the skills of the division. The division is involved in six international key intercomparisons: spectral irradiance, spectral responsivity, luminous responsivity, luminous flux, spectral diffuse reflectance, and spectral transmittance. The division is participating with selected laboratories in a secondary comparison on the measurement of aperture areas, and it is the pilot laboratory for this intercomparison as well as for the reflectance and for segments of the spectral responsivity intercomparisons.

The division is currently running regular short courses in photometry and radiance temperature and hopes to soon offer courses in spectroradiometry. These courses are unique and are, in the panel's estimate, of great value to the technical community. They give participants a unique opportunity to use state-of-the-art hardware under the supervision of truly competent instructors. A possible complement to these activities would be a series of online courses that could reach a wider audience and could also emphasize standard equipment likely to be found in mainstream laboratory and factory environments.

Division Resources

Funding sources for the Optical Technology Division are shown in Table 5.4. As of January 2002, staffing for the division included 40 full-time permanent positions, of which 35 were for technical professionals. There were also 15 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Panel members noted that possible reduction in the ATP program may have a significant adverse effect on the budgets of excellent ongoing programs.

Ionizing Radiation Division

Technical Merit

The Ionizing Radiation Division's mission is to support the NIST mission by providing national leadership in promoting accurate, meaningful, and compatible measurements of ionizing radiations (x rays, gamma rays, electrons, neutrons, energetic charged particles, and radioactivity). The division's mission statement embraces several activities, ranging from providing standards and reference materials

TABLE 5.4 Sources of Funding for the Optical Technology Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.5	5.4	5.9	6.2
Competence	1.0	0.9	0.7	0.7
ATP	1.0	1.0	1.1	0.9
Measurement Services (SRM production)	0.1	0.0	0.0	0.0
OA/NFG/CRADA	3.8	4.2	4.2	4.6
Other Reimbursable	0.7	0.6	0.7	0.7
Total	12.1	12.1	12.6	13.1
Full-time permanent staff (total)[a]	44	46	42	40

NOTE: Sources of funding are as described in the note accompanying Table 5.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

to developing methods and standards and conducting fundamental research. The overall conclusion of this review is that the division continues to accomplish outstanding scientific and technical work and to share its results with the broader scientific community through numerous publications and by participation in and leadership of workshops in topical areas of interest.

The Ionizing Radiation Division is organized primarily according to source technology and consists of three groups: Radiation Interactions and Dosimetry, Neutron Interactions and Dosimetry, and Radioactivity. These groups reflect the division's involvement in different source-based technologies: gamma and accelerated electrons, neutrons, and radioactive isotopes, respectively. The Radiation Interactions and Dosimetry Group also engages in computational methods and in the development of codes.

The division has taken a more assertive posture in the international standards community through greater involvement in international standards organizations and through interacting more frequently with other national laboratories than in past years.

The Radiation Interactions and Dosimetry Group is involved in four areas of scientific and technical activities: industrial dosimetry, medical dosimetry, protection and accident dosimetry, and theoretical dosimetry. The group provides NIST-traceable dosimetry to the medical and industrial communities and engages in the development of innovative, accurate dosimetry methods and techniques. In support of these uses, the group works on models and codes that increase the accuracy of dosimetry measurements and assist in the application and interpretation of dose and dose distribution in given use areas.

The highlight of the year was the division's response to the crisis brought about by the use of a bioterror agent, anthrax, in the mail. Ionizing radiation was found to be the most effective way of "sanitizing" contaminated mail and was adopted by the U.S. Postal Service. The Radiation Interactions and Dosimetry Group became extensively involved in calibrating the electron beams (EBs) at the two toll irradiation service centers (which rent EB time and facilities to users) that were contracted by the U.S. Postal Service. Besides providing needed dosimetry and using calculations to show dose distributions, the group developed strong working rapport with the operators of these facilities. The division chief became the coordinator for the interagency task force set up by the Office of Science and Technology Policy (OSTP) to address this issue. The division has thus assumed extensive new responsibilities that include dealing with OSTP, the newly created Office of Homeland Security, and appropriate agencies on a frequent and regular basis. Having expertise and infrastructure in place at NIST as a national resource allowed the division to respond in a timely fashion to this national need.

Industry is accepting the use of spin resonance to read alanine dose effects and is undergoing a transformation to this dosimetric method, which is founded on a stronger scientific basis than are the previously preferred techniques that are based on color changes in radiochromic films. A recent report[3] describes a NIST Internet-based "e-calibration" service for these measurements; the service is progressing smoothly. Alanine-coated films from a reputable supplier will help in this transformation process. The acceptance of the technique could be enhanced if the division took the lead in conducting alanine dosimetry intercomparisons among the providers of gamma- and electron-beam services that are used for medical product and food irradiation, as it is doing in "sanitizing" the mail for the U.S. Postal Service. One such study was conducted by the National Physical Laboratory in the United Kingdom and the Risr National Laboratory in Denmark on behalf of the European Union. The study yielded significant empirical results, indicating the precision of alanine as a dosimetry system in the hands of industry and national laboratory experts. This work illustrates the potential long-term impact of improved dosimetric techniques. The division should foster this alanine method by giving it appropriate priority in all areas.

Both the industrial and medical applications rely on the Radiation Interactions and Dosimetry Group for calibrations to a recently refurbished national reference ^{60}Co beam. Given differences in geometry between this beam and an older, weaker ^{60}Co source, some imprecision in dose comparisons between the two beams has been found, requiring characterization of a new ^{60}Co standard therapy source for the calibration program. However, the variation of a few tenths of a percent, depending on dosimeter positioning, may be more than adequate for using the older beam as an alternative source but not as the national reference source for calibrations.

The use of ^{60}Co in medicine as a source for external-beam radiation is rapidly decreasing, so it is essential that NIST develop standards for more conventional complex treatments used routinely in the clinic and prepare to address newer modalities such as intensity modulated radiotherapy with linear accelerators. The division's plan to acquire a 6- to 20-MeV medical linear accelerator from Varian is noteworthy, in that calibrations could then be made using equipment comparable to that found in the medical community. Attempts to force-fit such calibrations using the old accelerator in the Medical-Industrial Radiation Facility should be abandoned.

Many of the division's successes are the result of strong theoretical expertise. The division has been a major contributor to today's major transport codes, through both code development and data archiving. In response to panel recommendations, the division augmented its computational and theoretical expertise by hiring an individual with outstanding credentials in these areas. Although the Radiation Interactions and Dosimetry Group is small, NIST remains one of the few national centers supporting theoretical development and applied calculations in radiation dosimetry. Many of the needed calculations are so specific to standards and calibrations that they are not likely to be done by other research groups or supported by other laboratories because of the lack of expertise in these areas. An example of such work

[3]Desrosiers, M., et al., "e-Calibrations: Using the Internet to Deliver Calibration Services in Real Time at Low Cost," *Radiation Physics and Chemistry* 63:759-763, 2002.

is that presented in *Radiation Protection Dosimetry*.[4] The method was crucial for the evaluation of doses to the Russian residents exposed in the Techa River area.[5] Currently, the group is working on calculations of wall corrections for NIST standard graphite-walled cavity-ionization chambers to determine changes in ^{60}Co, ^{137}Cs, and ^{192}Ir air-kerma standards and on development of relativistic impulse-approximation calculations of Compton scattering of photons from bound atomic electrons (for updating of the NIST photon interaction database). Such calculations are essential for the precise determination of absolute doses and for ensuring the quality of national databases (e.g., NISTIR 6573 [2000]). In today's scientific climate, such expertise could best flourish if it were more involved in specific end-user and customer issues.

The Neutron Interactions and Dosimetry Group benefits greatly from having a unique, world-class facility to use in its research programs and industry support projects—namely, the cold neutron source at the NIST Center for Neutron Research (NCNR). The group's activities center on fundamental neutron physics, standard neutron fields and applications, and neutron cross-section standards. The Neutron Interactions and Dosimetry Group provides industrial support for instrument calibration, electric power generation, radiation protection, national defense, radiation therapy, neutron imaging, and magnetic resonance imaging.

The group has performed some of the most precise measurements ever taken of neutron lifetime using an in-beam technique. Measurements were completed for the coherent neutron scattering lengths of hydrogen, deuterium, and ^{3}He. Large-diameter ^{3}He spin filter cells were produced that extended polarization lifetimes. A 0.9-nm neutron monochromator was developed and tested for ultracold neutron production. This group was also responsible for producing and implementing a set of high-quality B-10 depositions used as part of a new international intercomparison for thermal neutron fluence rates. The group has developed a new cryogenic calorimeter for direct lifetime measurements; it is used to recalibrate the National Standard Neutron Source more accurately. Some of the applications arising from the fundamental work of this group include a neutron spectrometer that will be used for homeland defense research and a ^{3}He laser polarization measurement technique that has potential as a low-cost imaging technique for medical applications.

The group's interaction with diverse collaborators from the academic community and from other government laboratories remains strong, and its rate of publication remains high. The success of NIST researchers and collaborators in obtaining peer-reviewed support speaks of the importance and quality of the work from this group. Its activities in the area of neutron dosimetry have demonstrated leadership in national and international forums. Involvement with national laboratories in Germany and the United Kingdom in dealing with intercomparisons of thermal neutron fluence measurements is noteworthy.

The Radioactivity Group continues to be involved in four principal areas of scientific and technical activities: standards and methods, metrology in nuclear medicine, metrology and monitoring related to the environment, and quality assurance and traceability. This group is largely responsible for establishing and maintaining the primary standards for radioactive counting. The group focuses on preparing radioactive standards SRMs, developing calibration methods, and providing NIST traceability to cus-

[4]Seltzer, S.M., A.A. Romanyukha, and V. Nagy, "Monte Carlo Calculations of the Dose Distribution in Teeth Due to Internal Exposure from ^{90}Sr: Application to EPR Tooth Dosimetry," *Radiation Protection Dosimetry* 93:245-260, 2001.

[5]Romanyukha, A.A., S.M. Seltzer, M. Desrosiers, E.A. Ignatiev, D.V. Ivanov, S. Bayankin, M.O. Degteva, F.C. Eichmiller, A. Wieser, and P. Jacob, "Correction Factors in the EPR Dose Reconstruction for Residents of the Middle and Lower Techa Riverside," *Health Physics* 81:554-566, 2001.

tomers in fields ranging from nuclear medicine and radiopharmaceuticals to environmental monitoring and nuclear power. As a result, it is very customer oriented.

In addition to maintaining and disseminating the primary standards for radioactivity, the group characterizes reentrant ionization chambers, or "dose calibrators," as secondary standards for nuclear medicine; evaluates and remeasures nuclear decay properties; and performs work designed to exercise and maintain its expertise in radiochemistry and analysis methodology. Its evaluation of 5 alpha spectrometry analysis algorithms to resolve overlapping peaks for ^{241}Am and ^{243}Am under typical low-level counting conditions was accepted for publication in *Applied Radiation and Isotopes*. Its recently published work in the *Journal of Radioanalytical and Nuclear Chemistry,*[6] describes an alternative statistical approach for the evaluation of interlaboratory comparison data.

The group provides measurement and calibration support for the development of standards and metrology for nuclear medicine, including new and existing radioimmunotherapy agents and devices. Considerable progress has been made over the past year in developing quantitative destructive assay techniques for pure beta emitters such as ^{32}P used in coronary stents and as intravascular brachytherapy sources in balloon angioplasty, as well as for ^{90}Sr-^{90}Y "seeds" also used for intravascular brachytherapy. Careful attention to detail by the experimenter enabled the development of a protocol that accounted for all possible losses during destructive chemical processing, including those in the chemical- and source-handling steps. The determinations of activity from this work serve two purposes. First, the activity measurement provides a "primary" standard that can be used to calibrate nondestructive "secondary" measurement methods using ionization chambers. Second, given the activity of a sample, radiochromic film measurements of the spatial distribution of the absorbed dose of the sample can be related to theoretical Monte Carlo dose calculations. The results for the destructive assay work for both the ^{90}Sr-^{90}Y "seeds" and the ^{32}P angioplasty balloon catheter sources have been published in *Applied Radiation and Isotopes*.[7]

Other notable efforts in the area of nuclear medicine metrology include a very extensive and methodical set of experiments to determine the effects of factors such as solution pH and ionic strength, the presence of chelators, and the choice of commercial scintillants on the accuracy of assays performed with the liquid scintillation (LS) technique. In addition, a new initiative is under way to assemble and evaluate a Triple Double Coincidence Ratio (TDCR) system that will obviate the need for tritium efficiency tracing. The TDCR was initially developed and demonstrated in France, and the Radioactivity Group should be commended for working in collaboration with French counterparts to bring this technology to NIST. Both of these efforts are timely and important, because LS is the preferred measurement method used by most laboratories, including NIST, for the quantitative assay of pure beta-emitters.

Metrology efforts associated with personnel and environmental monitoring require the ability to measure radionuclides at very low levels, and, 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. To provide closely matched standards to meet user needs, the Radioactivity Group engages in developing and characterizing "natural matrices" such as soils, sediments, biota, and biological systems contaminated

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[6]Inn, K.G.W., et al., "Standards, Intercomparisons and Performance Evaluations for Low-Level and Environmental Radionuclide Mass Spectrometry and Atom Counting," *Journal of Radioanalytical and Nuclear Chemistry* 248:163-173, 2001.

[7]Collé, R., "On the Radioanalytical Methods Used to Assay Stainless-Steel Encapsulated, Ceramic-Based ^{90}Sr-^{90}Y Intravascular Brachytherapy Sources," *Applied Radiation and Isotopes* 52:1-18, 2000; Collé, R., "Calibration of ^{32}P 'Hot-Wall' Angioplasty-Balloon-Catheter Sources by Liquid-Scintillation-Spectrometry-Based Destructive Radionuclidic Assays," *Applied Radiation and Isotopes* 54:611-622, 2001.

with naturally occurring radionuclides from the decay of uranium or thorium or by actinides and fission products resulting from human activities. Of particular note 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 Pu at or below the 20 μBq/L level. Three organizations—the University of Utah, LLNL, and LANL—are participating in this intercomparison and are being given "realistic" bioassay samples that contain ^{239}Pu, environmental levels of ^{240}Pu, and natural uranium. The results of the first intercomparison have been published in the *Journal of Radioanalytical and Nuclear Chemistry*,[8] and results of the second study are expected out in 2002. A follow-on, third intercomparison study is being planned. The next study is expected to be considerably broader and will include the absolute determination of amount and isotopic composition of both U and Pu in a wide range of matrices. This effort has obvious applications and will provide a needed exercise and evaluation of laboratories involved in assays related not only to occupational health programs but to nuclear nonproliferation and counterterrorism as well.

NIST is investigating the use of resonance ionization mass spectrometry (RIMS), with glow discharge atomization and CW laser excitation to measure long-lived, low-energy beta and x-ray emitting radionuclides that are not easily measured with 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 determination of absolute activity by completely bypassing the need for lengthy radiochemical separation procedures. Further, RIMS offers the advantage of measuring several isotopes simultaneously and being independent of the nuclear decay properties. Consequently, maintaining a viable and robust RIMS capability would reduce costs to customers for these types of analyses. Currently, RIMS is being evaluated for the determination of low levels of ^{135}Cs and/or ^{137}Cs in the presence of stable ^{133}Cs. Optical selectivity of 10^3 for ^{135}Cs and ^{137}Cs against ^{133}Cs was observed, and measurements on subpicogram samples have been demonstrated. Plans for the future include evaluating RIMS for the detection and measurement of Pu isotopes and atom trapping to achieve single-atom detection.

The Radioactivity Group has made considerable progress during the past year toward bringing online its double-focusing thermal ionization mass spectroscopy (TIMS) unit. Eventually this system will be the workhorse for providing accurate and precise measurements for both the total amount and the isotopic composition of samples containing ultralow levels of Pu. The applications for this capability are primarily for determining the environmental transport of Pu involved in site remediation efforts, bioassays, and treaty verification measurements in support of nuclear test ban and nonproliferation national security activities. Currently, efforts are ongoing to determine and optimize filament loading techniques, to push down the sensitivity to the desired level of 10^6 atoms. At the present time, the division has demonstrated the 10^9 atom level.

The storage photo-stimulable phosphor (SPP) imaging plate system is being evaluated as a means for determining and quantifying the distribution of radionuclides over large-area surfaces. To date, its usefulness for mapping the location of ultralow levels of radioactivity has been demonstrated, but its

[8] Inn, K.G.W., et al., "Intercomparison Study of Inductively Coupled Plasma Mass Spectrometry, Thermal Ionization Mass Spectrometry and Fission Trace Analysis of mBq Quantities of ^{239}Pu in Synthetic Urine," *Journal of Radioanalytical and Nuclear Chemistry* 248:121-131, 2001.

ability to quantify activity levels reliably and accurately has not yet been proven. However, this technique is being evaluated for possible use in measuring ultralow releases of ^{40}K from the degradation of concrete in bridge abutments.

The consolidation of the gamma-ray systems into one location and the conversion from an old, custom UNIX-based data acquisition system to a new, networked Windows-based, commercially available data acquisition system has been successfully completed. No adverse impacts were noted during the transition, and all of the detectors are now operable and intercalibrated over the appropriate energy ranges.

Over the past year the Radioactivity Group has made great strides toward reestablishing NIST as a world leader in radiometric calorimetry. In response to panel concerns, the dual-compensated cryogenic calorimeter—designed to operate at 8 K and to measure the absolute activity of nuclides that decay by pure beta emission and electron capture—has been upgraded. Substantial improvements have been made to the cryostat vacuum system, and additional modifications have been identified that are expected to improve the baseline stability and considerably reduce the parasitic heat losses between stages. The results of the work on the cryogenic calorimeter were presented at the most recent meeting of the International Committee for Radionuclide Metrology (ICRM) and have been accepted for publication in *Applied Radiation and Isotopes*. The group also installed and evaluated a new commercial isothermal microcalorimeter that operates at 303.5 K. Of particular note were modifications made to the microcalorimeter to allow absolute, NIST-traceable power measurements by incorporating specially designed and calibrated resistive heating elements within the source cell. Additionally, very meticulous efforts to calibrate the microcalorimeter over the power range from 15 to 250 μW for several sample holder configurations enabled calorimetric measurements of ^{90}Sr-^{90}Y brachytherapy seeds and a ^{32}P "hot wall" angioplasty-balloon-catheter and comparison with the results from destructive assay and ionization chamber methods. It is interesting to note that for the ^{32}P balloon catheter, excess heat was detected and identified as resulting from chemical reactions induced by the interaction of beta particles with the material composing the balloon. When this correction was applied, the "correct" value for the heat resulting from radioactive decay was obtained.

Program Relevance and Effectiveness

The Ionizing Radiation Division is a relatively small national laboratory in comparison with other federal laboratories, but its past successes and its future lie in maintaining and fostering a proper balance and synergy between expertise in basic research (where payoffs are usually both distant and uncertain) and calibrations, standards, and quality assurance (where dramatic discoveries or events are rare). Having in place a credible dosimetry system based on alanine enabled the division to respond to the use of electron beam irradiation as the select process for "sanitizing" presidential, congressional, and other mail from the anthrax threat. This exemplifies the need for maintaining expertise and resources and supporting developmental work in major areas of radiation research and technologies in order to deal with new developments and unexpected events.

The division maintains strong participation in national standards organizations, such as ASTM International, the American National Standards Institute, Digital Imaging and Communications in Medicine, and the Institute of Electrical and Electronics Engineers (IEEE). In response to previous panel suggestions, the division has enhanced its involvement in the international standards community though the International Commission on Radiation Units and Measurements, the International Electrotechnical Commission, and the International Committee for Radionuclide Metrology. Division personnel are members of key professional associations, such as the American Association of Physicists in Medicine and the Health Physics Society, and of national bodies such as the National Council on Radiation Protection and Measurements and the Council on Ionizing Radiation Measurements and Standards (CIRMS). The division has been attentive to national needs as spelled out by CIRMS, an independent, nonprofit coordinating council that draws its constituents from industry, academia, and government, and it assisted CIRMS in publishing its third triennial report on *National Needs in Ionizing Radiation Measurements and Standards*.[9] It is through these various organizations and through its direct contact with the scientific and industrial communities that the division stays abreast of current activities and is a key contributor in the fields of ionizing radiation measurements and standards.

The panel noted in its previous report that the medical and industrial communities require more frequent updates on developments and issues involving calibrations and dosimetry determinations, perhaps by means of status reports posted quarterly on the NIST Web site. For example, user community concerns over variances in air-kerma calibrations could be more readily calmed by more frequent communication. In some areas, the user community could benefit by division personnel assuming positions of leadership in organizations such as ASTM.

The Neutron Interactions and Dosimetry Group enjoys excellent industrial and academic collaboration, predicated on having use of a world-class facility, the ultracold neutron source of the NCNR and complementing this with outstanding nondestructive analytical capabilities such as the Neutron Interferometry and Optics Facility. These tools have enabled the group to engage in projects on the cutting edge of small-scale power generation: analysis of fuel cell membranes and investigations into ion transport in lithium batteries. The group also has excellent rapport with the nuclear power industry. The group performs an outstanding job of balancing these industrial concerns with fundamental research. However, the fundamental research projects are quite complex. The panel noted last year that generating an overview of these projects, including milestones passed and milestones expected, would benefit their management and assessment.

The Radioactivity Group responds well to its customer base but should be cautious in taking on efforts that overextend the group's resources. In this regard, a review of existing and needed SRMs should be made to enable a clearer delineation of the amount of effort and resources needed to support these SRMs. In fact, given the endless possibilities of generating SRMs based on various radionuclides, soils, and other contaminants, the division as a whole should develop a list of the most-needed SRMs and a justification for providing them, relying on some cost-benefit analysis.

The group is to be commended on its completion of a 4-year endeavor on the NIST Radiochemistry Intercomparison Program (NRIP) 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."

The division continues to support as well as develop new quality-assurance programs for federal, military, and private organizations, as requested. This effort includes setting standards, establishing and validating traceability programs, performing instrument calibrations, and participating in intercomparison programs. Currently, division customers include but are not limited to the Food and Drug Administration (FDA), the U.S. Army, the U.S. Air Force, the Department of Energy (DOE) and its associated national laboratories, the U.S. Nuclear Regulatory Commission, and the nuclear medicine and power industries through the Nuclear Energy Institute.

[9] *National Needs in Ionizing Radiation Measurements and Standards.* CIRMS, October 2001. Available online at <http://www.cirms.org/NR3info.htm>.*National Needs in Ionizing Radiation Measurements and Standards.* CIRMS, October 2001. Available online at <http://www.cirms.org/NR3info.htm>.

The division's theoreticians are probably the only body of researchers in the United States committed to the theoretical aspects of standards and calibrations. This provides indispensable support for the division's experimentalists. A recent reduction in staffing for this effort was of concern, but the panel is pleased to see that a new staff member has been added. To be most effective, this effort now requires well-defined strategy and goals.

Among the division's homeland security proposals, the development of a national program for the assurance of security x-ray inspection systems is within NIST's proper charter. Such a measurement quality assurance (MQA) is warranted, given the proliferation of security x-ray systems. Caveats should be clearly expressed to others in government and at NIST on the limits of x-rays to detect certain materials—that is, plastic-like explosives, composite cutting tools, and so on—that terrorists have selected as materials of choice.

The division is to be commended on its intent to acquire a medical linear accelerator for use in developing standards for patient treatments and its studies of dosimetry and materials effects. It is unfortunate that it took a national calamity to compel the division to put forth a proposal for a state-of-the-art accelerator facility, its Irradiation Testbed Facility (ITF), as noted in one of its homeland security proposals. Given ITF's costs, the division would show prudence by preparing an alternate plan for certifying a state-of-the-art, high-current industrial electron-beam accelerator as a reference source. This might be most useful if done in collaboration with a university.

The division possesses outstanding expertise and facilities in the neutron area, and its resources might be better used in leading and coordinating activities centering on neutron systems for sensing explosives, contraband, and nuclear materials with other national laboratories rather than replicating well-established efforts that have been in progress for many years elsewhere. As in its work with the U.S. Postal Service, NIST and the Ionizing Radiation Division best serve national interests by being a resource of expertise and a neutral facilitator. Such expertise in coordinating and facilitating programs could be brought to bear in the neutron detector area and would be of greater value than attempting to develop specific instrumentation.

Division Resources

Funding sources for the Ionizing Radiation Division are shown in Table 5.5. As of January 2002, staffing for the division included 38 full-time permanent positions, of which 34 were for technical professionals. There were also 3 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Attrition and retirements have enabled the division to attain a more balanced age profile. The division is to be commended for bringing very bright junior scientists onto its staff.

While the division will benefit from personnel transfers to support its involvement in homeland security issues, this may not compensate for a declining budget for the division's core operations, particularly if the costs of additional responsibilities are to come in part from existing budgets. While competitive funding from other federal agencies, such as DOE, can enhance the quality of programs, the division itself should have a strong enough base budget to sustain its essential role in measurements and standards.

CIRMS has expressed concerns over adequate division staffing as the council develops Measurement Program Descriptions (MPDs) that are intended to express to the division national needs in radiation measurements and standards. The growing demands in the medical area and emerging issues such as food irradiation warrant staff support as well as needs in the area of occupational radiation

TABLE 5.5 Sources of Funding for the Ionizing Radiation Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	4.5	4.3	4.3	5.3
ATP	0.2	0.2	0.2	0.0
Measurement Services (SRM production)	0.1	0.1	0.1	0.1
OA/NFG/CRADA	1.6	1.5	1.7	2.2
Other Reimbursable	0.9	1.2	1.4	1.4
Total	7.3	7.3	7.7	9.0
Full-time permanent staff (total)[a]	36	33	38	38

NOTE: Sources of funding are as described in the note accompanying Table 5.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

protection. The division, as does industry in general, faces the difficulty of finding recruits with adequate background in nuclear chemistry and radiochemistry. The division could help address this nationwide talent shortage by working in cooperation with the American Chemical Society and with a supportive organization such as CIRMS to give presentations to undergraduates on the merits and challenges involved in radiation science and technology.

Within the operational practices at NIST, the Ionizing Radiation Division (and perhaps other divisions as well) could benefit by having an adequate equipment repair and maintenance budget under the discretion of the division chief, but independent of the research, standards, and calibration budgets. For example, x-ray calibrations had to be suspended for more than 4 months, not only until a replacement x-ray generating tube could be found but also while internal budget funds were sought to acquire it. There should be a budget strategy for routinely replacing and decommissioning outdated equipment.

With the expanding numbers of applications of brachytherapy, the growing acceptance of seed implantation as a method for treating prostate cancer and other malignancies, and the involvement of a greater number of potential suppliers and diverse sources and configurations, the division's resources for seed and other brachytherapy calibrations are being strained. Recent responsibilities include the establishment and maintenance of air-kerma-strength standards for new prostate seeds, including the transfer of standards to secondary laboratories and the characterization of transfer instrument (wall-ionization chambers) response. Recognizing the importance of strong input and oversight by NIST scientists, the division should take a close look at how much of this calibration work can be turned over to ADCLs or secondary standards laboratories.

Given its shift in priorities and emphasis, the division might wish to consider realigning its resources into groups centered upon its customer base: the medical area, the industrial area, and the occupational and radiation protection areas, instead of being aligned by source technology. This would be comparable to the way in which CIRMS has organized its scientific and technical committees and should enable the division to be more responsive to its customers.

Time and Frequency Division

Technical Merit

The mission of the Time and Frequency Division is to support the NIST mission through the provision of measurement services and research in time and frequency and related technology to U.S. industry and science. The division is organized in four technical groups: Time and Frequency Services, Atomic Standards, Ion Storage, and Optical Frequency Measurements. The groups are small, and the group leaders function primarily as technical leaders within their areas. The common theme of time and frequency technology produces a strong connection among the groups, and there are positive interactions among them.

The Time and Frequency Division continues to define the international state of the art in current-day time and frequency standards and services and in the long-range development of improved standards and services. In the past year, the division realized a major goal of research carried out over the last two decades—an optical frequency standard using trapped ions. More details of this accomplishment are given below.

The cesium fountain standard, NIST-F1, has now supplanted the cesium beam standard, NIST-7, as the primary time standard. The frequency uncertainty of NIST-F1 was improved in the past year from 1.7×10^{-15} to 1.2×10^{-15}. This latter evaluation is the best ever reported by any laboratory to the Bureau International des Poids et Mésures (BIPM). This improvement was made possible by more closely controlling light shifts, keeping the number of atoms in each bunch constant, and incorporating a better quartz flywheel oscillator and new software for the line center servo. In the near future, diode lasers will be replaced by a Ti:sapphire laser for further improvement. The division is working on improvement in the reliability of NIST-F1 to provide more regular data that will preserve NIST-F1's weight in the BIPM time scale.

Improvements to the fountain technique are being carried out in parallel with the operation of the NIST-F1 standard. In part, these advances are made possible by the existence of parallel programs. In particular, NIST has built a transportable fountain clock, in which the Cs atoms are not thrown as high and the atom cloud does not expand as much, so the signals are larger than those of NIST-F1, allowing quicker comparisons of clocks. Using this clock, the division is investigating transverse cooling of the tossed atoms with the goal of improving the number of detected atoms.

Design and construction of the next-generation cesium fountain clock, NIST-F2, have begun with several improvements. NIST-F2 might have no on-axis lasers, thereby avoiding light shift effects; the interrogation region will be cooled to liquid nitrogen temperature to eliminate the uncertainty of the black body shift (currently 3×10^{-16}); and NIST-F2 will also use an improved transverse cooling technique.

The division is participating in a NASA-led consortium to build a Primary Atomic Reference Clock in Space (PARCS), based on laser-cooled Cs atoms. One of the requirements peculiar to these very low atomic velocity clocks is immunity to vibration. To minimize the sensitivity of the clock to vibration, a phase modulation of the second Ramsey field is employed rather than the usual technique of switching the frequency back and forth between opposite sides of the central fringe. This technique has other advantages—reduced line pulling and cavity pulling effects—which have led to its use on NIST-F1.

The Optical Frequency Measurements Group continues to ride the wave of momentum and opportunities created by the demonstration of an optical frequency comb. Femtosecond pulses from a mode-locked laser are injected into a nonlinear microstructure fiber and emerge as periodically spaced phase-coherent modes spanning an octave of frequency. By frequency doubling a low-frequency mode and

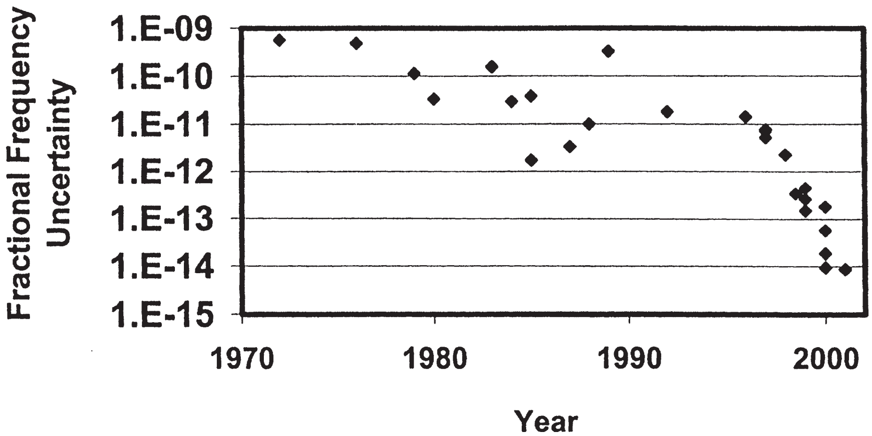

FIGURE 5.2 Improvement in frequency uncertainty of optical frequency measurements.

comparing it with a high-frequency comb mode, it is possible to connect the pulse repetition frequency of the mode-locked laser to the frequencies of the comb modes in a phase-coherent way. If the pulse repetition frequency is phase-locked to a stable reference, such as a hydrogen maser, the frequency of every mode in the comb is then known with the precision of the frequency of the reference. Such a system allows any frequency in the spectral range of the comb to be measured with the uncertainty of a primary frequency standard.

The dramatic recent improvement in the accuracy of optical frequency measurements is shown in Figure 5.2. It is not an exaggeration to state that this approach is revolutionizing the strategy for next-generation primary frequency standards. Standards and clocks much better than the current primary standard should be realized in the next decade.

To date, frequency combs have been produced with a center wavelength of 800 nm using Ti:sapphire lasers. It is highly desirable to extend this approach to the optical-fiber communication bands at 1.3 and 1.55 μm for telecommunications applications. The specific goal is to support wavelength-division multiplexing. The division has begun design and assembly of a mode-locked Cr:forsterite laser that emits ~1.3 μm. This is referenced to the 657-nm line of calcium after division by 2. Significant applications of the femtosecond comb to measurements of atomic frequencies were also demonstrated in the past year. For example, the 282-nm transition of a single Hg^+ ion and the 657-nm transition of a calcium ion were measured with the frequency comb, and the measurements are now limited by the uncertainty in the frequency of the primary cesium standard.

In the summer of 2001, the Time and Frequency Division passed a major milestone—the demonstration of an optical frequency standard with a microwave output—which was made possible by the frequency-comb work. The resultant clock benefits from the high Q (the ratio of transition frequency to linewidth) of an optical transition, the cycle-counting capabilities that exist at microwave frequencies, and the translation of the extreme performance of optical frequency standards to the microwave range provided by an optical frequency comb. A 282-nm optical frequency standard with $Q \sim 10^{14}$ (a single trapped Hg^+ ion) is coupled to a frequency comb that bridges an octave in the optical spectrum. As described above, the phase-locking of comb modes spaced ~1 GHz apart produces a phase-coherent pulse train at that repetition rate. Thus, a microwave output phase-locked to the optical frequency standard is obtained. This device has a frequency stability of 7 parts in 10^{15} with a 1-second averaging time and has the potential to achieve uncertainties 1,000 times better than those of the current best standards.

Other avenues for more sophisticated clocks based on atom entanglement are being pursued. In a standard clock, with no systematic shifts and with uncorrelated atoms, the projection noise decreases as the square root of the number of atoms. If the atoms can be entangled, the projection noise can decrease directly as the number of atoms; this improvement has been demonstrated using two trapped ions. Entanglement also allows the use of ions with good clock transitions but no suitable readout transitions. Specifically, efforts are under way to explore the use of two trapped ions: one, the "clock ion," has a high Q transition, and the other, the "logic ion," is used to read the state-of-the-clock ion. The coupling between the two is via the vibrational modes of the ions in the trap.

While originally pursued by NIST for its possible applications to clocks, the use of atom entanglement for quantum computing is now being investigated by the division. Two significant advances were made in the past year. First, the dominant source of decoherence in the atom trap was found to be patch electrostatic fields arising from Be coating the trap electrodes. Improved shielding of the electrodes from the Be source has reduced the patch fields by a factor of 30, allowing ions to remain coherent for a correspondingly longer time. It appears to be difficult to store a sufficient number of ions in the trap at one time in order to make a quantum computer with 10 or more qubits. Instead, the proposed approach is to shuttle ions into and out of a computing region. A central question is whether or not the ions, which are in superposition states, will maintain their coherence. In its second advance of the past year, NIST has demonstrated that they do maintain coherence. It is noteworthy that the NIST approach to quantum computing is the only one currently being pursued that is scalable in size.

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 (currently 4×10^{-15} at 1 second), limited primarily by the atomic velocity. Due to its lower Q (by 2 orders of magnitude), it does not appear to be a serious competitor to the mercury ion standard for use as a primary standard, but it is useful for comparisons of optical standards. In the past year, the temperature of the calcium ions was reduced to 4 μK (from 1 mK) by a quenched narrow line cooling approach. The cooling will be extended to three dimensions, which should result in a factor-of-30 reduction in the atomic velocity and a substantially improved clock.

DARPA has expressed interest in development of a low-power chip-scale clock with a total volume of 1 cm^3. Theory and experimental demonstrations at NIST confirm the feasibility of such chip-scale clocks. In one scheme, coherent population trapping is used to eliminate the necessity for a microwave cavity, thereby enabling major reductions in size. Instead, the light from a laser diode is frequency-modulated at half the Cs hyperfine spacing. When the modulation frequency is precisely half the hyperfine spacing, the optical transmission is maximized. Locking the microwave frequency to the maximum transmission gives a clock with performance comparable to an Rb gas-cell clock and several orders of magnitude better than the best quartz oscillator. With DARPA support, it is quite likely that a small-size, low-power, and moderately good performance, gas-cell clock will be developed and adopted for commercial manufacture. Such a clock will generate breakthrough applications for military and commercial telecommunications use.

The stability of the NIST coordinated universal time (UTC) time scale with respect to the UTC disseminated by BIPM continues to improve, most recently through the use of five commercial hydrogen masers with cavity autotuning. Improvements in the comparison of time scales have been achieved by application of two-way time transfer and carrier phase common view techniques. The division has also produced a special time scale, AT1E, which is very useful for comparing frequency standards at very high precision over extended periods of time. It also added a new comparison and measurement system at 100 MHz to enable better measurements of local high-performance frequency standards.

NIST defines the state of the art in the construction of microwave-frequency synthesizers for the primary frequency standards. Most new standards have or will have NIST-built synthesizers. NIST has now delivered 10 copies of its microwave synthesizer for frequency standards. These are carefully designed to have low phase noise (roughly 20 dB below commercially available synthesizers) and very high phase stability with ambient temperature changes. The most dramatic improvement in performance in the past year was the reduction of the temperature coefficient to 0.1 ps/K. It is noteworthy that these synthesizers have a basic architecture that supports generation of interrogation signals for cesium (9.192 GHz), rubidium (6.834 GHz), hydrogen (1.414 GHz), and mercury (40.5 GHz). To avoid taxing limited staff resources, the division should investigate whether construction of these sources can be assumed by a commercial partner.

Efforts are ongoing to develop phase and amplitude noise measurement capability and techniques at frequencies up to 100 GHz. This regime, far beyond the range of commercial instrumentation, has applications in high-speed digital devices, broadband telecommunications, and radar. Using external funding, the division has worked to develop techniques for and to perform phase noise measurements of pulsed radar signals. The division's capabilities in these areas are unique in the world.

Time transfer via GPS common view techniques, including carrier phase, and two-way satellite transmission remains at the state of the art. The division has demonstrated the world's best frequency comparison via time transfer at 5×10^{-16}. The rapid advance of the accuracy and stability of primary frequency standards is stressing the capability of international frequency comparison via these techniques. This continues to be a highly important area for work and innovation, and such work is in the division's plans.

The service functions of the division are focused primarily in the Time and Frequency Services Group and include telephone and network time messages and radio transmissions from WWV, WWVB and WWVH. The Internet servers at NIST now handle traffic of 350 million hits a day and continue to grow at 8 percent per month.

Program Relevance and Effectiveness

The Time and Frequency Division provides technology-specific services as well as fundamental research in these areas of technology.

In the view of the panel, the most important division product is its outstanding research in the science and technology of atomic frequency standards. This is work that has enormous leverage in the hands of scientists and engineers engaged in new product development in industry. The success of the division in responding to this need is demonstrated by its 83 publications and 71 invited talks in 2001. The division also organized six tutorials or workshops in 2001, teaching time and frequency science, technology, and techniques.

In March 2001, the division hosted a workshop on chip-scale atomic clocks. Theoretical work by division scientists has become the enabling basis for proposed atomic clocks with unprecedented small size (1 cm^3), low power (30 mW), and performance (1×10^{-11} at 1 hour averaging time). The division is working to confirm and expand the understanding of the physics of these miniature clocks, which would have defense applications of significant impact. The division should evaluate, by informal survey or otherwise, the time and frequency industry's interest in topic-specific workshops with the goal of having one such workshop each year. The objective is to transfer NIST knowledge and technology to U.S. industry more efficiently. One suggested topic is "RF carrier cancellation techniques."

The accuracy of NIST-F1 is the world's best data submitted to the BIPM at 1.2×10^{-15}. The interplay of the time scale, the primary frequency standards, and the precision time transfer programs are synergistic with multiple, yet coordinated, objectives. The precision time transfer programs allow intercomparison with other international laboratories; the time scale provides a continuous and stable reference; and the primary standards provide the ultraprecision data points, which serve to calibrate the time scale. Regular and periodic evaluations of the primary standards, necessary to represent NIST performance in the international BIPM time scale, is a challenge to division staff. In order to preserve the standing of the NIST primary frequency standard in the international BIPM time scale, the panel recommends that the division adopt an approach to primary frequency standard design that allows a more continuous evaluation.

It is noteworthy that the division is in the process of upgrading the time scale measurement system that is the backbone of the time scale, replacing 20-year-old equipment that is exhibiting both performance and reliability issues.

The increased radiated power from WWVB has made a reality of the availability of accurate (<1 second error), very low cost wall clocks and wristwatches that reset automatically to the WWVB signal. Signal strengths of 100:V/m, upon which these clocks rely, are now available throughout the continental United States. Because of its limited resources, the division should prepare a cost-benefit analysis for the operation of WWV and WWVH transmissions, with the goal of eventual discontinuation of services that offer limited benefit to the United States.

Traffic at the division's Internet time service (www.boulder.nist.gov/timefreq/service/its.htm) continues to grow, seemingly without bound, reaching 350 million hits per day and growing at 8 percent per month, as stated above. The view of the panel is that continued expansion of this service represents an unjustifiable load on division resources. More aggressive efforts should be made to move this to industry, in accordance with the multitier calibration capability structure more common in other calibration functions in the United States. As a last resort, the option should be considered of consciously limiting future expansion of support for this service, with an anticipated degradation in quality of service. Continuation of the free NIST service may have perceived aspects of competition with industry.

Division Resources

Funding sources for the Time and Frequency Division are shown in Table 5.6. As of January 2002, staffing for the division included 35 full-time permanent positions, of which 30 were for technical professionals. There were also 6 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

In an environment of nearly level funding, the division must adopt a strategy that responds accordingly. It is important to actively select roles to embrace and those to defer, since there will never be enough resources to do everything. This should not be taken as a suggestion that activities be terminated. In fact, it is difficult to identify activities of the division that are not worthwhile. Rather, the panel suggests exploring alternative methods for delivering some of the division's services, so that the expertise of the division can be focused on its long-term goal of providing continually improving standards.

The division continues to attract and retain high-quality personnel. A strength is the management system under which individual scientists are encouraged to show initiative. The division is staffed at a level sufficient to continue good progress on scientific and technical projects, and overall, the division is reasonably well supported. However, enough outstanding ideas and projects exist in the division to

TABLE 5.6 Sources of Funding for the Time and Frequency Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	6.0	6.0	6.1	5.9
Competence	0.0	0.1	0.6	0.5
ATP	0.1	0.1	0.2	0.2
OA/NFG/CRADA	2.6	2.5	2.8	3.6
Other Reimbursable	0.6	0.9	1.0	1.0
Total	9.3	9.6	10.7	11.2
Full-time permanent staff (total)[a]	40	39	39	35

NOTE: Sources of funding are as described in the note accompanying Table 5.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

keep a significantly larger staff very productively engaged. Management of the division is excellent; morale is high, and the staff enjoys a real sense of advancing the state of the art and enjoying the fruits of many years' worth of discovery and development as well as taking advantage of unexpected new techniques and opportunities.

University research in frequency and time standards is by now nearly nonexistent in the United States. As a result, NIST, through its postdoctoral programs, has become the best place for a promising physicist to learn the science and technology of atomic frequency standards. The National Research Council's postdoctoral program is the most visible of the NIST postdoctoral programs, and two NRC fellows are presently in the division. The division should explore a more aggressive approach to soliciting NRC postdoctoral researchers or other students with the goal of training more scientists and engineers in time and frequency science and technology, the end goal being to enhance NIST's role as an educational resource for U.S. industry.

The quality and quantity of laboratory space has been a problem for the division, but this problem is now being addressed. The Optical Frequency Measurements Group is acquiring newly renovated space, and the Ion Storage Group will receive 270 m^2 more space. The quality of space is as important as the quantity. The new space allocated to the Ion Storage Group will be temperature-, humidity-, and vibration-controlled. Having better laboratories will certainly enhance the productivity of the division. It is remarkable that staff have achieved what they have in their present laboratory space.

REVIEW OF JILA

This biennial assessment of the activities of JILA,[10] an institute administered jointly by the National Institute of Standards and Technology and the University of Colorado (CU), is based on a meeting of the

[10]Formerly the Joint Institute for Laboratory Astrophysics.

Subpanel for JILA in Boulder, Colorado, on February 14-15, 2002, and on documents provided by JILA. NIST participation in JILA formally occurs through the Quantum Physics Division of the Physics Laboratory. One member of the Time and Frequency Division is also a JILA fellow.

The members of the subpanel were Frances A. Houle, IBM Almaden Research Center, *Chair;* Dmitry Budker, University of California at Berkeley; Robert L. Byer, Stanford University; A. Welford Castleman, Jr., Pennsylvania State University; Richard J. Colton, Naval Research Laboratory; Mark A. Kasevich, Yale University; Michael D. Morse, University of Utah; Douglas O. Richstone, University of Michigan; and Ian A. Walmsley, Oxford University.

Technical Merit

According to JILA management, JILA's vision is this: "JILA, through its work at the frontiers of fundamental and measurement science, enables the future by creating knowledge that both advances understanding and improves the quality of life."[11] This new vision, presented in final form to the subpanel after its meeting in February 2002, dovetails very nicely with the overall mission of NIST to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life.

The present emphases of JILA are on advances in precision measurement; low-temperature states of gaseous matter; laser-based metrologies for extremely sensitive, highly resolved, and ultrafast processes; and characterization of chemical processes. These focus areas are in excellent alignment with the broader mission of NIST. The research activities pursued at JILA actively promote the U.S. economy and the nation's quality of life by providing essential measurement capabilities and reference data developed by some of the most productive and capable scientists in the world. These contributions provide the scientific basis for optical and nanoscale technologies that are becoming increasingly important for the further development of high-technology industries in the United States. Continued support for the outstanding human resources at JILA, for the infrastructure of the institute, and for its partnership with the University of Colorado, will ensure that this world-class research institute retains its ability to provide a critical foundation for future U.S. technology development.

JILA has been incredibly successful in achieving the goals now expressed in the JILA vision and NIST mission statements. Ample evidence indicates that the JILA fellows work at the forefront of science in many areas. The most obvious demonstration of the institute's achievements comes in the areas of atomic, molecular, and optical physics, where two JILA fellows were awarded the 2001 Nobel Prize in Physics for their work on Bose-Einstein condensation and the physics measurements that followed from the creation of this unique state of matter. However, while this honor is certainly the highest-profile award given to JILA fellows in the past 2 years, it is by no means the only recognition JILA staff have received. Other honors included a Department of Commerce Gold Medal, a MacArthur Fellowship, a Presidential Early Career Award for Scientists and Engineers, the Joseph F. Keithley Award, the Maria Goeppert Mayer Award, the Samuel Wesley Stratton Award, the Franklin Medal, the Federal Laboratory Consortium Technology Transfer Award, and several elections as fellows of various professional organizations (the American Academy of Arts and Sciences, the Optical Society of America, and the American Physical Society).

In general, the subpanel finds that the work of other JILA fellows and research groups is of comparable quality to the work under way in the areas of atomic, molecular, and optical physics.

[11]Personal communication, J. Faller, National Institute of Standards and Technology, to Frances A. Houle, February 2002.

Indeed, the subpanel emphasizes that the work leading to the Nobel Prize did not occur in a vacuum. Those results simply could not have been accomplished without the cooperative and collaborative atmosphere engendered at JILA, which in large part succeeds because it brings together the most capable and productive scientists that can be found and then lets them pursue their ideas across laboratory or disciplinary boundaries with little hindrance. JILA provides a model of productive interdisciplinary research that both serves the teaching and research communities on the CU campus and meets the needs of NIST.

An important contributor to JILA's success is the relatively unusual structure of the institute. It is truly a joint program equally reflective of both partners, a national laboratory and a university. At JILA, NIST provides significant resources and strong ties to industry, while CU provides students and a variety of strong interdepartmental collaborations. This year, the subpanel was very pleased to learn that the newest JILA hire had a joint appointment in the CU Department of Molecular, Cellular and Developmental Biology. This outreach to a group beyond JILA's traditional collaborating departments (Physics, Chemistry, and Astrophysical and Planetary Sciences) is to be commended, and the relationship appears to be blossoming, with plans both at JILA and in the Physics Department to increase the biophysics expertise at CU. New modeling activities and potential collaborators for the JILA biophysicist in the Applied Mathematics Department also are positive steps for strengthening and expanding JILA's interactions with CU faculty in a wide variety of fields.

Currently, the activities of the JILA fellows fall into five loosely defined categories: fundamental and precision measurements, optical and nonlinear optical physics, materials interactions and characterization, atomic and molecular interactions and chemical physics, and astrophysics. The subpanel finds that all of these programs continue to produce work of a very high degree of technical merit. In addition to these established programs, JILA is also moving into the area of precision measurements on biophysical systems. This expansion represents a significant extension of the core competencies of JILA into one of the most important developing areas of science.

Highlights

The effective appointment and professional development of young JILA fellows is at the heart of the achievements highlighted below and of other recent JILA accomplishments. At the subpanel's last review of JILA in 2000, many of the recently hired fellows were just settling in to their laboratories and had not established their reputations within the relevant scientific communities. Now, 2 years later, they are well known and well respected by their peers. The identification of promising young fellows, the appointment of fellows to JILA, and the investment of time and energy in the professional success of each fellow lay the foundation for JILA's success, and current JILA fellows and management have embraced this process and have demonstrated a deep commitment over time to this goal. The consequence of this focus on appointment and career development is an institute that has young, enthusiastic staff and is capable of identifying and exploring new directions and new ideas. Enthusiasm for new avenues of inquiry pervades JILA, and this culture helps attract the best visiting fellows, postdoctoral scholars, graduate students, and staff. JILA is an exceptional place at the very top ranks of the world's institutions of science and precision measurement technologies. Below are a few examples of recent achievements that demonstrate how JILA has opened new fields of inquiry and why JILA fellows will continue to do so in the future.

JILA investigators continue to lead the world in the exploration and exploitation of Bose-Einstein condensates (BEC) and Fermi degenerate quantum gases. This work has been recognized with numerous national and international awards, including the 2001 Nobel Prize in Physics. Significant achievements since the subpanel's last review include manipulation of a Bose gas via tunable interactions, pioneering studies of vortex systems, and record levels of degeneracy in Fermi systems. A stunning recent result is the observation of coherent oscillation between molecular and atomic condensates. In addition to these advances in fundamental science, JILA personnel are also pursuing potential technology applications through a JILA-led DOD Multidisciplinary Research Program of the University Research Initiative, geared toward the development of a new class of rotation and acceleration sensors based on guided-atom techniques.

Two JILA fellows have been at the forefront of developing several important applications for optical combs. Remarkable advances have accrued since the subpanel's last review. Accomplishments include the combining of two phase-stable mode-locked lasers to produce pulses that are shorter than those of each of the individual lasers, reduction in timing jitter between two lasers to better than 1 fs, the controlled synthesis of pulse trains with widely separated frequencies, and the application of stabilized pulse trains to atomic and molecular spectroscopy. Perhaps the research result with the most impact to date is the demonstration of an "optical clock," a clock based on an optical frequency standard. This clock provides a tool through which the standards in two very different domains—the optical and the radio-frequency areas—can be brought together. This merger will have important and positive consequences for anyone wishing to use calibrated excitation and measurements with better than 10^{-15} precision. A measure of the significant difference this work has already made is the increasingly commonplace presence of optical combs in metrology and time-standards laboratories throughout the world as the combs replace the cumbersome frequency chains used over the past decade. The comb technology is approaching the point at which it will be at the center of defining clock standards; this will be a truly revolutionary transition to have occurred in so short a time.

The precision measurement expertise at JILA is also being used to extend measurement technologies to the nanoscale regime and to the level of single-molecule detection. Using an apertureless near-field scanning optical microscopy technique based on an atomic force microscopy, JILA staff can now probe dimensions down to the 2- to 3-nm-length scale. This method is being used to measure the fluorescence of semiconductor CdSe quantum dots and thereby study their excitation and decay. The study of "blinking" of individual quantum dots provides detailed information about the electron-hole pair formation and recombination in quantum dot structures. The ability to measure these phenomena with a precision of 2 to 3 nm could impact future generations of semiconductor devices.

Technical Merit by Program

Fundamental and Precision Measurements. Recently, JILA has built a strong program in optical frequency synthesis. Two years ago, it became apparent that the combination of nonlinear self-phase modulation in glass fibers with very stable mode-locked laser sources could produce a comb of optical frequencies that extended beyond an octave in frequency range. The important characteristic of this technique was that the nonlinear interaction was adequate to produce a broadband "white light" comb of modes but not so nonlinear that it also added phase noise to the comb of frequencies. Therefore, it was possible for the red end of the frequency comb to be frequency-doubled and phase-locked to the blue end of the comb. Further, with additional control, the comb of modes from one laser could be phase-locked to that of a second laser, thus allowing the extension of the frequency comb over an even greater frequency interval. In addition, one frequency of the comb can be phase-locked to an optical frequency standard, thus stabilizing the entire comb of frequencies. This work, led by a recently appointed JILA fellow, has allowed JILA to become the leader in optical frequency synthesis and optical frequency stabilization. The frequency stability achieved at JILA already rivals that of the best microwave frequency standard, and the projected frequency stability is expected to reach a full 2 orders of magnitude beyond that available in the microwave region. As a result of JILA work, optical frequency synthesis, optical frequency standards, and optical frequency clocks are now making giant strides toward becoming the best-available time standard.

JILA continues to lead the world in the development of new instruments and techniques for absolute gravimetry, which has important scientific applications in measurements of the gravitational constant, *G,* and technological applications in characterization of Earth's gravitational field. This work continues to thrive and has evolved in two significant directions since the subpanel's last review: the first is development of a compact, low-cost, field-deployable gravimetry instrument, and the second is a new way to measure *G*. In each case, the work is of high quality and impact. For example, a low-cost, high-accuracy, absolute gravimeter will be of substantial economic benefit to oil and mineral exploration companies, while a new measurement of *G* contributes to the world community's effort to resolve the significant discrepancies observed among recent measurements of this constant.

Another ongoing project is the comparison of the primary frequency standards located at NIST Boulder[12] and at the German NMI in Braunschweig, Germany. Each of the clocks has an accuracy of $1\text{-}2 \times 10^{-15}$ in fractional frequency, and the two standards were found to agree within $4\text{-}5 \times 10^{-15}$. This is the first time that this type of comparison has been made to this level of accuracy. Nonetheless, NIST personnel are already actively investigating how the accuracy of the comparison might be improved if better transfer techniques could be utilized. This work is important for improving frequency standards because it will enable an independent assessment of the estimation of contributions of systematic offsets to the output of the cesium fountains.

The fundamental and precision measurements area has traditionally been the point of the strongest interactions between JILA and NIST, supported in a large part by long-term personal relationships between JILA and NIST employees. A number of the parties to these interactions are nearing retirement or have retired. However, the subpanel was pleased to see that some of the new JILA fellows have recognized the value of interactions with NIST and are developing connections with NIST staff, particularly in the area of time and frequency standards.

Optical and Nonlinear Optical Physics. At the forefront of an international effort, work at JILA in the coherent control of the high-harmonic interactions that generate soft x-rays is heralding the beginnings of attosecond science. JILA scientists have shown that some control can be exerted over the highly nonlinear interaction of ultra-intense optical pulses with atomic gases in such a way as to optimize the generation of a particular harmonic peak. Moreover, the group has developed new measurement capabilities to understand the mechanism of the enhancement; these techniques may prove to be applicable to other highly nonlinear optical processes. Overall, the groundbreaking ultrafast laser technology developed at JILA will form the basis of a new generation of attosecond light sources. For example, the ultrafast laser source at JILA has already been used to measure surface adsorbate dynamics with unprecedented clarity. Now the short-time dynamics of charge transfer and reorientation in molecules on surfaces can be studied in a spectral region that provides clear evidence of charge state changes, with temporal resolution previously only available in the optical regime. This new coherent light source will have wide impact in several other areas of physics, chemistry, and materials science. Another potentially important application is the facilitation of information transmission at a very high data rate.

[12]Although carried out by the Time and Frequency Division, this work is overseen by a JILA fellow.

Another innovative project is the work on guiding ultracold atoms (including condensates) along lithographically patterned magnetic guides on chips. JILA was a leader in efforts to guide atoms in the same way that photons are guided down optical fibers, and a notable recent success is the demonstration of a switch for atoms. (A beam of atoms is guided into a "switchyard" and can be directed to one of two different outputs, depending on the magnetic field, applied using a current-carrying wire in close proximity to the beam.) This technique is the first step toward true atomic waveguiding, in which the DeBroglie wavelength of the atoms is comparable to the size of the waveguide structure. The long-term goal of the project is to enable ultraprecise sensing of gravitational gradients, which could have significant implications for remote sensing, geodetics, and navigation. This project is a collaboration between two JILA fellows, and its success illustrates why JILA and the JILA culture are so productive. First, JILA has enabled two physicists with very different backgrounds to come together to work on a common problem. Second, the culture at JILA values and encourages work such as this, which is aimed at turning cutting-edge science into state-of-the-art technology.

Another of the striking successes rising from the support of collaborative and applied research at JILA is a collaboration between a JILA fellow and faculty in the Department of Electrical Engineering. This combined expertise has enabled the development of an optical autotuning filter for detecting electromagnetic signals in the microwave region. Specifically, this technology provides a means to identify and isolate the largest signal in a broadband, broad area, microwave field using the photorefractive effect, by imposing the microwave signal modulation on a laser beam and filtering it via nonlinear optics. The signal recovery achieved with this optical method is as good as or better than the best reported in the literature, illustrating how nonlinear optics can be used to provide a robust and reliable technology.

Materials Interactions and Characterization. Materials-related activities at JILA mainly focus on research driven by basic scientific discovery, although the results of some projects have the potential to be relevant to important communications tools or other modern technologies. Some of the highlights of the research in the materials area are described below.

One project focuses on the formation and dynamics of optical solitons (solitary waves found in optical systems) in Kerr-lens mode-locked Ti:sapphire lasers. The spectrum shows theoretically predicted soliton instabilities, or "explosions," appearing as a sudden, intermittent increase (then decrease) in the temporal length of the soliton. The explosions are sensitive to the intracavity dispersion characteristics of the laser. This work may have applications in telecommunications, where use of dispersion-managed solitons is a candidate for a future long-distance communication method.

Another project is studying coherent responses in semiconductors. Although there has been intense work in the community over the past decade on applying ultrafast time-resolved spectroscopic methods to semiconductors, JILA scientists have recently made significant progress on identifying new coherent interactions that had eluded previous efforts. The unrecognized contributions of excitation-induced shifts of the band-edge during excitation show up in nonlinear transient polarizations that can be measured via four-wave mixing. In recent experiments, the transient four-wave mixing signal shows a split peak that can only be explained by many-body interactions among optically excited electrons and holes. These effects are usually ignored in phenomenological models of the interactions, but they may be important in understanding the operation of high-speed laser diodes and light-emitting diodes.

A third project has demonstrated that it is possible to produce a fast, multiple input AND gate using molecular wave packets. First, shaped femtosecond laser pulses have been used to create a coherent superposition of rovibrational molecular states in a gaseous sample of Li_2. The resulting quantum wave packet functions as a fast, multiple-input AND gate, with six input values which shape the femtosecond pulse and with the output being read out after a short time delay by a photoionization detection scheme. In this proof-of-principle study, the evolution of the quantum wave packet performs the computation, and the result is readily generalizable to hundreds of input values, which would control the shaped femtosecond pulse.

In a fourth project, the growth of InGaN materials is being investigated using an in situ scanning tunneling microscope to probe the formation of InN islands in the growing samples. The formation of islands is critical for uses of these materials as high-efficiency light emitters, and the project aims to determine the growth conditions necessary for achieving InN island formation. Although this project has not yet generated useful results, the instrument required for the study has been built, and the results of the study will clearly be relevant to the optoelectronics industry and to the broad NIST mission.

In addition to the projects described above, a number of other investigations are under way in the materials area. Work on growing a regular nanostructured array of Ge quantum dots on a lithographically patterned silicon lattice is progressing. No inherent limit on the size reduction of the quantum dots is observed; instead, the limit appears to be determined mainly by the size of the etched features. Finally, several experiments are under way on the chemistry and physics of chemical vapor deposition from silicon-containing gases. One uses light scattering to examine the formation of silicon particles, and another uses threshold ionization mass spectrometry to examine the flux of Si_xH_n radicals to surfaces. An understanding of these processes is important to manufacturers of hydrogenated amorphous silicon photovoltaics and thin-film transistors.

Atomic and Molecular Interactions, Chemical Physics, and Biophysics. Increasing need exists for optical methods to measure the properties of nanoscale objects with sizes below the diffraction limit of light, and JILA researchers have made impressive progress in this area in the past 2 years. The combined effort of two JILA groups resulted in the development of new methods in apertureless near-field scanning optical microscopy (NSOM) that overcome the depth limits constraining other techniques. Resolution improvements down to the 2- to 3-nm-length scale have been demonstrated. Scattering and extinction near-field microscopy have been used to gather impressive data on scattering cross sections that can provide important benchmarks for testing theoretical models of near-field interactions. The findings have enabled evaluation of the scattering cross sections in the presence of an evanescent wave, as a function of distance above the surface. Enormous scattering enhancements for gold nanospheres at less than 5-nm resolution have also been obtained.

In a related significant development, apertureless NSOM has been extended into the domain of near-field fluorescence microscopy, enabling the use of atomic force microscopy (AFM) tips to influence the near-field excitation of dye-doped nanospheres and semiconductor quantum dots down to 6 nm; nearly a thousand-fold enhancement of the near-field laser intensity has been achieved. JILA fellows, in collaboration with a NIST theory group in Gaithersburg, have successfully modeled the strong sensitivity arising from tip elongation, by employing image dipoles generated in the prism when the laser-polarized AFM tip approaches surfaces within one tip radius, including the lightning-rod-antenna effect.

Novel optical microscopy techniques enabled by some of the work described above have allowed other projects to focus on single-molecule spectroscopy. One especially significant result is the discovery and explanation of a “blinking” phenomenon found in the fluorescence behavior of ZnS overcoated CdSe and InP quantum dots on surfaces. Kinetic information about electron-hole pair ejection and recombination demonstrates that there is a wide range of time scales (varying over 5 to 6 orders of magnitude), so the process for these single quantum dot structures must be distinctly nonexponential. In other studies, confocal microscopy methods are being employed to image biomolecules, with the goal of studying the intercalation kinetics of DNA tethered to surfaces. A fluorescence technique for time-resolved imaging of single biomolecules in gel electrophoresis is being developed in order to investigate the kinetics of conformational changes in real time.

In a related area, a new JILA scientist was hired by NIST to create a program in biophysical measurement. This exciting new program merges optical-based measurement science, a strength of JILA, with single-molecule studies of fundamental biological processes. The current focus of the program is on measuring the motility of single biological molecules, for example, the movement of enzymes such as RNA polymerase along double-stranded DNA or the repair by recDNA of damaged DNA.

Seven years after their initial observation of BEC, JILA researchers continue to lead the world in the study of ultracold, dilute atomic gases. The exceptionally creative and important ideas being developed at JILA have vitalized and catalyzed research in this area throughout the international scientific community.

Experimental and theoretical work over the past 2 years has focused on the study of interacting Bose and Fermi systems with tunable mean-field interactions, vortex dynamics and vortex lattices, mechanisms for efficient production of degenerate Fermi gases, spectroscopy in very high density samples, techniques for efficient and cost-effective production of these ensembles, and techniques to guide and manipulate ultracold atoms. Each of these studies is of very high scientific and technical caliber. Theoretical work in this area continues at the highest level and includes studies of molecular condensate formation and fermion pairing, as well as ultracold atom collisions. This work will have impact on fundamental science and on technological applications. Scientifically, the study of these systems challenges existing theoretical paradigms, paradigms that are at the forefront of AMO and condensed matter physics. Technologically, BEC and degenerate Fermi systems may enable new generations of ultrasensitive force sensors and time standards. From a broader perspective, the current revolution in nanoscience and quantum information science hinges on understanding the interface between quantum and classical systems. Study of macroscopic quantum BEC and degenerate Fermi samples provides a unique and fruitful path to further knowledge in this area.

In a study with astrophysical implications, a JILA fellow has developed a new theoretical method of calculating the rate of dissociative recombination of H_3^+ ions struck by low-energy electrons. The distinguishing feature of the calculation is the recognition of the role of Jahn-Teller coupling in the recombination process. This phenomenon has been almost universally ignored in previous theoretical attempts, but it is of critical importance in the proper treatment of the dissociative recombination phenomenon in high-symmetry ions such as H_3^+. The Jahn-Teller interaction also figured prominently in ultrafast measurements performed by another research group on the vibrational dynamics of Ag_3 formed in a nonequilibrium linear geometry by photodetachment of an electron from Ag_3^-. The subsequent bending into the near-equilateral configuration, followed by vibrational randomization within the triple-minimum Jahn-Teller potential energy surface, could be clearly followed with 100-fs time resolution in this experiment. Ultrafast cluster dynamics have also been probed by photodetachment of an electron from the $OH\text{-}(N_2O)_m$ system, leading to the formation of the potentially reactive $OH\text{-}(N_2O)$ system. The aim of these studies is to learn to prepare bimolecular reaction precursors at well-defined initial conditions for subsequent investigation by ultrafast pump-probe spectroscopy. This approach can yield valuable new information about chemical reaction dynamics in such systems.

In a study of two-electron ejection from a helium atom subjected to an intense pulsed laser field, another group has been able to determine that the dominant mechanism of two-electron ejection is a "recollision mechanism." Here, the intense laser field accelerates the ejected electron so that it collides with the helium ion again, causing a second electron to be ejected. This is related to processes that are used to generate high harmonics of pulsed laser radiation, and an improved understanding of these processes is likely to result from this work.

Another JILA group has succeeded in employing a high-order harmonic of a femtosecond pulsed Ti:sapphire laser to generate photoelectron spectra as a function of the time following preparation of the system by a pump laser pulse. This is a major breakthrough, allowing ultrafast probes of chemical dynamics in the gas phase or on surfaces, using the well-understood method of soft x-ray photoelectron spectroscopy. Another important ultrafast investigation has produced a method to implement an evolutionary algorithm to vary the frequency-dependent phases that are contained in a femtosecond pump pulse, so that a particular molecular outcome is optimized. These results will be important for future work employing molecular wave packets to develop quantum-computing algorithms.

Another project uses high-resolution infrared (IR) laser spectroscopy to detect and investigate the reactivity of free radicals, such as those that play an important role in chemical processes of atmospheric or industrial significance. A unique combination of methods involving plasma discharge methods of formation, long-path-length laser absorption methods, and slit supersonic jets is producing spectroscopic data of unprecedented detail. The findings are especially valuable for laser remote sensing of these species. Some attention is also being given to systems where the Born-Oppenheimer approximation is invalid. Similar state-of-the-art techniques are being employed to investigate the state-to-state dynamics for several systems, with emphasis currently on hydrogen abstraction reactions. The result is data that will illuminate crucial details governing the reaction dynamics of atom-diatom systems; this approach has yielded full quantum specifications of the products at far higher resolution than acquired in crossed-beam time-of-flight methods. Direct IR laser absorption techniques developed as part of this work are being used to investigate quantum-state resolved dynamics of reactions at gas-liquid interfaces. The focus is on heterogeneous reactions that may be important in the atmosphere as well as those operative in internal combustion processes.

Astrophysics. The vibrant Astrophysics Program continues to produce excellent results. Its high output of publications, almost entirely in refereed journals, is an indication of the quality of this group, and its work continues to serve the scientific communities and granting agencies that are their primary customers. Some of the highlights of the results from the past 2 years follow.

One project is a study of the various modes of accretion onto black holes. JILA fellows have shown that under some circumstances, the accretion flow near the black hole is coupled to magnetic fields that thread the black hole itself. Consequently, most of the energy dissipation in the disk occurs closer to the black hole than expected. This result makes important predictions for future x-ray observatories. In another project, the same hydrodynamical methods have been employed to study the formation of planets in protoplanetary disks. These disks are also studied spectroscopically at JILA, using data obtained with the Hubble Space Telescope and other satellites. This spectroscopic work provides information on the chemistry occurring within the disks and is relevant to other JILA activities. Another project using hydrodynamical simulation is the work on Supernova 1987a. A JILA fellow's prediction that the supernova ejecta would run into a surrounding ring of gas is now being confirmed by experimental data, and the next phase of his work focuses on studying the developing interaction between the ejecta and the ring by interpreting data from NASA satellites.

Fluid dynamical simulations are also being used to study the sun. Helioseismology (the study of low-amplitude solar oscillations in millions of normal modes) permits measurements of many physical parameters (such as temperature and rotation speed) deep within the sun; it has allowed scientists to discover that, contrary to theoretical expectations, the sun does not rotate with velocity constant on cylinders. The data instead seem more consistent with rotational velocity constant along radial rays at large distances from the center. Simulations at JILA are being used to test the theory that this behavior is a consequence of turbulence in this region in the sun.

Other projects include a comparison between the calculations of the spectrum of anisotropies in the cosmic microwave background and the observations of the background. The goal is to find the best-possible estimates of the fundamental parameters of the universe—the mass and energy densities, the curvature of space, the baryon density, and the expansion rate. The project on formation of pregalactic magnetic fields in the youthful universe with no seed fields is focused on understanding the generation of the first magnetic fields, which has been a theoretical challenge for some time.

In the 2000 assessment report, the subpanel noted that JILA's efforts in gravitational wave research (with connections to the international Laser Interferometer Space Antenna [LISA] program) represented an important synergy between the technology of precision measurement and metrology and the activity in theoretical astrophysics. Unfortunately, one key departure and a critical retirement have greatly reduced the level of activity in this area. In the United States, the center of the LISA program has shifted from JILA scientists (who initiated the project) to NASA centers. Nonetheless, one emeritus JILA fellow is still on the LISA team and remains a spark plug for this project.

The Role of Astrophysics at JILA. As JILA works on defining its vision and planning for its future, one key issue will continue to be the place of astrophysics at JILA, as has been discussed in past reports. The original mission for JILA focused strongly on laboratory astrophysics but has evolved a great deal since then. When NIST formally withdrew from supporting astrophysical research in the mid-1990s, the NIST section of JILA focused on developing a world-class center of excellence in atomic, molecular, optical, and chemical physics. In the late 1990s, the decision was made that the astrophysics fellows still at JILA, on the CU side, would leave JILA and take up residence in the CU Department of Astrophysical and Planetary Sciences, where they all already had faculty appointments. However, since that time, it has become evident that a lack of space on campus will preclude such a move. Therefore, it appears at this time that JILA expects astrophysics to remain as a significant element of JILA and expects the JILA astrophysics fellows to continue to play an active role in JILA management. This shift is evident in the broader vision for JILA that includes the astrophysics community as well as ongoing chemical and physics research and in the discussion of whether an experimental astrophysicist might be hired to take advantage of potential synergies between precision laser measurement expertise and applications of this technology for future space missions.

Currently, there are eight JILA fellows with joint appointments in the CU Department of Astrophysical and Planetary Sciences. All are theoretical astrophysicists. Significant research collaborations between the astrophysicists and the other JILA fellows were not evident at this time, but both groups do appear to value the casual intellectual interactions that occur due to their collocation. Hiring an experimental astrophysicist with interests in the development of cutting-edge astronomical detector technologies could certainly help strengthen the overall relationship of these two groups. Areas of possible synergy would include transition-edge superconducting devices, interferometry and high-precision metrology, gravitational wave physics and precision gravity, and submillimeter detector development. The subpanel acknowledges that finding the right person for this position, someone who is simultaneously an excellent scientist and a superb technologist, would be difficult, but the rewards would be better bridges between the JILA atomic, molecular, and optical sciences group and the JILA astrophysicists and between JILA and the CU Astrophysical and Planetary Sciences Department as a whole.

Program Relevance and Effectiveness

JILA is a vibrant interdisciplinary research institute of the highest caliber. The results and products of JILA's programs serve a number of potential customers, including researchers in academia, industry, and government, and the public. Appropriately, JILA's primary focus is on scientific and technical communities. The JILA fellows communicate information about ongoing and completed projects to this audience in a variety of ways, including presentations, invited talks, public talks, and publications. These outputs have served researchers well, and JILA clearly continues to be dedicated to these forms of dissemination. During 2000 and 2001, the number of technical papers increased from the previous review period to 340 publications (up by 56 percent), the number of invited talks doubled to 360, and the number of guest researchers rose from 50 to 56. However, apparently because of budget considerations, the number of visiting fellows at JILA will be significantly reduced for the 2002-2003 season. The visiting fellows program brings distinguished scientists to JILA for longer periods of time (4 to 12 months) than might otherwise be possible; these scientists bring new expertise to JILA, and their visits often lead to fruitful, long-term collaborative relationships. This program is a key component of the intellectual vitality of the institute and is an integral part of its ability to serve the scientific community. The subpanel believes that ways to reinvigorate this valuable program should be explored.

JILA interactions with industry do not seem to be as productive as its relationships with the academic community, and these industrial interactions do not appear to be a high priority for JILA. There were no distinguished visitors from industry during the last two review periods (i.e., since 1998). In the mid-1990s, JILA did have a small but growing industrial outreach program managed by one of the JILA fellows, but this activity has all but disappeared. Currently, the one relevant formal activity is the National Science Foundation (NSF)-funded Integrative Graduate Education, Research, and Training (IGERT) Optical Science and Engineering Program (OSEP) at the University of Colorado. This program funds graduate students working in optics and includes a summer internship in an optics-intensive U.S. company. Several students at JILA participate in this program.

Many of the areas of research under way at JILA are particularly interesting to industry, such as the work on time and frequency standards, on advances in ultrafast lasers, and on phase control of ultrafast lasers for precision measurements. JILA fellows, staff, and students would definitely benefit from ongoing interactions with companies that share their interest in the research and technologies central to JILA programs. Also, support for the U.S. economy, in which high-technology industries play a key role, is a key element of the NIST mission. The subpanel learned in conversations with individual fellows that informal interactions do occur between fellows and researchers from both small and large companies, and the subpanel applauds these interactions. However, there was no sign that any formal program was in place to support or encourage these activities, nor was there any indication that these impromptu exchanges of information with individuals from industry were being tracked so that company people might be contacted again for follow-up or for input about or dissemination of future projects of potential interest to these individuals or to others at their companies.

In addition to increasing awareness and tracking of industrial interactions, JILA should also consider establishing a corporate affiliates program to facilitate interaction with companies. The benefits of such a program would include improved visibility of JILA within the broad industrial community, insight into a new set of problems and research areas, expanded employment opportunities for graduating students, and potential increased support for JILA research programs.[13] A final element of increased management attention to the issues surrounding industrial interactions should be the careful consideration of a formalized set of policies to guide effective and appropriate technology transfer. JILA currently lacks guidelines in this area, and hence the technology transfer that is occurring takes place on

[13]Over the longer term, affiliates programs in similar laboratories have produced relationships that provided up to 10 percent of the total support for the laboratory.

an ad hoc basis by individuals adopting what they perceive to be a proper approach. While acknowledging that different relationships will have differing degrees of formality, the range of possible approaches should be clearly spelled out so that JILA scientists are not at risk when faced with the complex options in the technology-transfer arena. JILA should work with both NIST and the University of Colorado to develop a more formal process for technology transfer, both to assist with meeting the public good of transferring technology to the industry and to assist its own fellows, scientists, postdoctoral scholars, and students in understanding and managing the potential conflict-of-interest issues.

For people outside the academic and industrial science and technology communities, JILA also has activities designed to reach a more general audience. All JILA fellows teach CU classes, and one astrophysics fellow is developing interactive Web-based teaching tools, now being adopted by others in the group, that are among the most innovative and exciting in the country. JILA fellows participate in the CU Wizards program, which provides monthly public presentations by CU professors to elementary school students on various topics in science. JILA personnel also interact with local museums; one fellow has been actively involved in the development of interactive exhibits (including a black hole flight simulator) with the Denver Museum of Nature and Science. Recently, existing public outreach efforts have been augmented by the many requests for the two Nobel laureates to give scientific and public lectures about their work.

Finally, a distinctive example of the broad dissemination and wide impact of work done at JILA and NIST is the important and increasingly visible program in time standard distribution. This activity is currently maintained by a JILA fellow from the NIST Time and Frequency Division, which operates an Internet time service that responds to requests for time in a number of standard computerized formats. As of January 2002, these servers were receiving roughly 350 million requests per day, and the demand was growing at a compounded rate of 8.5 percent per month. The success of this service, utilized worldwide, rests on the technology for accurate dissemination of time developed at NIST over many years. For example, the JILA fellow has recently received patents for techniques for dissemination of authenticated time stamps.

JILA Resources

Funding sources for the NIST Quantum Physics Division are shown in Table 5.7.

In the 2000-2001 academic year, NIST contributed roughly \$6.5 million to JILA; the University of Colorado contributed roughly \$5.5 million to JILA; and outside contracts, grants, and visitor contributions provided roughly \$11.7 million (of which about \$6.6 million was from NSF). This brought the total 2000-2001 funding for JILA to approximately \$23.7 million.

Staffing for the NIST Quantum Physics Division currently includes 12 full-time permanent positions, of which 10 are for technical professionals. There are also 7 nonpermanent and supplemental personnel, such as postdoctoral fellows and part-time workers. Among the University of Colorado staff, there are 16 JILA fellows.

JILA counts 10 Quantum Physics Division researchers and 1 Time and Frequency Division researcher among its fellows and fellow-track members, with expertise in chemistry (2), physics (8), and biology (1). On the CU side, the 18 fellows and fellow-track members are on the faculty of the CU Chemistry (2), Physics (7), and Astrophysics (9) Departments.

It is hard to think of another institution in the world today besides JILA that carries out such truly important work and accomplishes so much with the limited resources available to it. As previous subpanels have pointed out, JILA's success is attributable to several key elements: the partnership between CU and NIST, the synergy and talents of the researchers, adequate and flexible funding,

TABLE 5.7 Sources of Funding for the NIST Quantum Physics Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	3.6	3.8	3.9	5.2
Competence	0.3	0.5	0.9	0.4
ATP	0.2	0.2	0.2	0.6
OA/NFG/CRADA	0.6	0.7	0.5	0.3
Other Reimbursable	1.1	1.3	1.3	1.3
Total	5.8	6.5	6.8	7.8
Full-time permanent staff (total)[a]	11	11	11	12

NOTE: Sources of funding are as described in the note accompanying Table 5.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

excellent technical support, inspired management, a stable and very effective staff, and the physical proximity of its researchers. It is clear to the subpanel that JILA's leadership has focused considerable effort on the management of these elements of success, in recognition that decline in any of them could seriously weaken the institute. Although largely fruitful, these efforts have met with significant challenges in the past several years, and especially so since the last subpanel review in 2000. These are discussed in the remainder of the report. Left unsolved, these challenges could seriously impair JILA's ability to do leading-edge science and to recruit and retain talented researchers and will significantly impact the return on NIST's investments in JILA.

Personnel

Fellows. Six new fellows have been hired over the past 3 years, and JILA's ability to attract, hire, and mentor outstanding young scientists is a testament to the exciting and supportive atmosphere that pervades the JILA culture. The subpanel was greatly impressed by the superb scientific programs that each of these fellows is developing and commends the management for continuing to provide a unique and nurturing environment in which these young scientists can excel.

However, the success of JILA and its high visibility in the scientific community has a downside: the risk that key individuals may be the targets of recruitment by other institutions. The fellows clearly believe that JILA is a wonderful environment in which to work, but resource and infrastructure limitations certainly do exist; as in all government laboratories, salaries and funding can be an issue. While JILA appears to be able to provide competitive salaries at the early stages of careers, it is possible that the more prominent senior fellows from NIST could receive higher compensation in academia, and other institutions may be willing to offer superior salaries, start-up packages, and infrastructure. On the other hand, NIST's flexibility in its ability to allocate internal resources to particular areas can work to its advantage, as supplemental research funds can be an important component of a retention package. In addition, the spirit of collaboration and synergistic activity that pervades JILA and the excellence of its shops and support people make the institute a very attractive work situation and in general have enabled the retention of sought-after fellows.

For the first time in many years, a NIST-employed JILA fellow is leaving JILA for another institution. Some turnover at JILA is not by definition a negative event. While the departure of this fellow and his large group working in the area of physical chemistry will definitely be a loss, it is also an opportunity for technical evolution of the JILA programs and a chance to consider new directions. As noted above, JILA has clearly demonstrated the ability to hire and nurture outstanding young scientists, and the subpanel is confident that JILA will continue to be able to attract exciting new researchers to the institution. However, transitions are always difficult, and the period following the departure of this fellow in the summer of 2002 will be a very complicated time owing to a number of factors, related in part to the relationship between JILA and the CU Chemistry Department.

The most important decision facing JILA will be what scientific fields to recruit in during the next few years. This issue is not a new one and has been raised in past subpanel assessment reports. The subpanel continues to note that a clear vision for the future of JILA would help guide these decisions. Such choices also must be made in the context of the expertise and programs of the current fellows, and that context will change significantly with the departure of the large group that represents roughly half of the current physical chemistry efforts at JILA. Where JILA will go from here is not clear, and the subpanel feels most strongly that strategic decisions must be made on the basis of how best to maintain JILA's extraordinary ability to produce cutting-edge work in science and technology and support the NIST mission. At this juncture, it is important and healthy for JILA to consider the centrality of the physical chemistry effort to the institute's mission. Should the released resources—especially space—be used to develop other research areas such as biophysics or instrumental astrophysics? What would be the long-range consequences of a reduced level of physical chemistry activities in JILA? Several current technical programs, such as the Bose-Einstein condensate work, incorporate physical chemistry expertise and techniques into their projects; would the loss of this discipline within the institute compromise JILA's ability to move into new frontier areas in the future?

Determining the answers to questions such as these is a complicated process. The subpanel was deeply concerned to learn that this process may be subverted by factors that are inappropriately limiting JILA's ability to consider recruiting in all appropriate technical areas. While each fellow at JILA is officially associated with either CU or NIST, all have an appointment in a CU academic department. The NIST fellows are usually adjunct professors, but they teach and train CU students at JILA just as the CU fellows do. Therefore, JILA hiring decisions are not made entirely on the basis of JILA's needs, but in the context of the needs of various departments. This system can be very productive, as seen in the recent hiring of a biophysicist at JILA who will bring to campus new expertise of interest to the Physics Department; the Molecular, Cellular, and Development Biology Department; and possibly the Applied Mathematics Department. However, the system depends heavily on collegial relationships between JILA and the non-JILA faculty in the departments. In the physical chemistry area of the Chemistry Department, the relationships are not cordial, and there is concern at JILA and on the subpanel that this tension may make it impossible to find a mutually acceptable physical chemist to hire.[14]

JILA will not be without physical chemistry immediately upon the departure of the fellow in 2002, but the anticipated retirement of another physical chemist in the next year or two will reduce JILA to one

[14]Hiring a JILA fellow who is not associated with a CU department is not an option, as the new fellow would be severely hindered in her or his efforts to build a research group involving graduate students as well as postdoctoral scholars.

experimental physical chemist. One is not a community, and there is a real risk that physical chemistry at JILA may disappear altogether. This would be acceptable only if JILA had decided that such a shift in its focus was appropriate and necessary and had planned a smooth transition and alternative approaches to providing JILA fellows with access to needed physical chemistry expertise. If, however, the relationship with the Chemistry Department forces JILA into a decision that is not based on a careful assessment of the centrality of physical chemistry to JILA's mission, that will be a very unacceptable outcome.

JILA management, the JILA fellows, NIST, and CU are facing a very challenging set of circumstances, and the subpanel urges all concerned to work toward resolution of the situation. In the past, the subpanel has suggested that JILA consider establishing a committee to liaise with university departments, but it is clear that a more formal and extensive effort will be needed. Both NIST and CU benefit greatly from the success of JILA, and JILA's health as an institution depends heavily on the identification of common interests with CU's academic departments. Therefore, the subpanel recommends that NIST and CU work together to ensure coordination and healthy collaborations with relevant CU departments, including Chemistry; Physics; Astrophysical and Planetary Sciences; and possibly the Molecular, Cellular, and Development Biology Department and the Applied Mathematics Department. One possible approach would be for NIST and CU to jointly establish a committee charged with examining the current status of the working relations between JILA and the relevant CU departments. The committee would report findings and recommendations to both NIST and CU.

Even if the situation with the Chemistry Department is resolved, the transitions of the next few years still have the potential to make this time an unsettled period at JILA. The loss of a prominent colleague after a serious retention effort is demoralizing. The vacancies associated with the retirement of a number of senior fellows over the next 5 or so years also have the potential to create tension at an institution run to a remarkable degree by consensus processes. Special care must be taken to assure that a departure does not stimulate additional departures that could lead to the collapse of the extraordinary and productive environment now at JILA.

Management. JILA's management structure and governance structure with a rotating chair of JILA and a permanent chief of the NIST Quantum Physics Division appears to work well. The absence of a formal mechanism for long-range planning seems unusual, but it appears to be mitigated by a shared sense of vision among some of the senior fellows. While the institute makes sensible and even inspired decisions about its future within its present structure, a more formalized planning mechanism could improve JILA's ability to respond to difficult situations (such as the hiring decisions to be made in the wake of this year's departure of a fellow and issues related to facilities problems and improvements). The management of the NIST Quantum Physics Division, which is a subset of JILA, has additional responsibilities to ensure support of the NIST mission. The subpanel finds that although a great deal of attention is paid to hiring and resource matters, long-range planning and management of industrial interactions and intellectual property are not addressed at the same level.

Staff, Students, and Postdoctoral Researchers. The subpanel was impressed by the positive morale among staff, students, and postdoctoral researchers at JILA. They all appeared to feel privileged to be associated with the institute and seem to receive significant satisfaction from participating in important and interesting work. The comments below reflect topics that were discussed when the subpanel met separately with each of these groups.

The support staff is highly capable and the electronics and machine shops at JILA are of very high caliber; access to these JILA shops, technicians, and support people is a key contributor to JILA's success. There is a strong esprit de corps among JILA employees, who feel appreciated by the scientific staff. A new program is a series of Tuesday meetings, in which the fellows describe specifically for the staff the technical work they are supporting. These meetings are very valuable and are appreciated by the staff. Continued enhancement of modes of communication will reinforce the atmosphere of mutual respect that pervades the laboratory.

Graduate students also appeared to be very happy at JILA. The only potential concern expressed was the variation in the level of support provided, as stipends and benefits depend on the students' home department and on whether they are affiliated with OSEP. Finally, the postdoctoral scholars expressed similar levels of pride at being associated with JILA. They were particularly impressed with its infrastructure. The major inconvenience for them related to the policy of making postdoctoral scholar appointments for 1 year at a time, even though these appointments are typically renewed for a total appointment of 2 or 3 years. While the rationale for this approach is certainly sensible, it poses a real burden for foreign scholars, who must return to their home countries to reapply for a visa after the first year. This absence is disruptive to research and expensive for the researcher. The fellows may wish to examine the tenures of their past postdoctoral scholars and consider whether an initial 2-year appointment would be in the best interests of the research groups and of JILA.

Facilities

The previous subpanel review called attention to several challenges posed by JILA's aging and inadequate physical plant. The shortcomings fall into two categories. First, there is a serious, long-term, crowding problem; the amount of space is insufficient to accommodate the activities of all of the JILA fellows and their groups. Next year, JILA will have a temporary reprieve on this front when a significant part of the physical chemistry activity leaves and a good deal of laboratory space will be freed up. While this newly available space will relieve the crowding in the short term, a long-term solution is still needed. There is funding in the 2005 NIST budget projection for vertical expansion of the present building, and corresponding funding exists in the CU plan. The subpanel did not see detailed plans for this expansion, but the funding levels discussed (a total of about $6 million) do not seem to be consistent with the magnitude of the desired expansion (adding about 50 percent more space). Additionally, the contemplated plan for expansion involves the addition of stories above and below the present building, which will be rather disruptive to the ongoing research activities of the laboratory. If JILA obtains the funding and goes forward with this approach, a plan to mitigate the disturbance associated with the construction will be needed before work starts.

The second class of facilities issues relates to problems associated with the physical condition of the current facility. The building is showing its age, and the environmental control in many of the laboratories is inadequate. While the skills and creativity of JILA scientists and staff are compensating for the dust, inadequate ventilation, and poor thermal control in the JILA laboratories, the subpanel believes that this is a temporary and inefficient solution to the problems. Efforts are being made to find funding for improvements (CU recently agreed to provide $500,000 specifically targeted at improving temperature control), and technological solutions are currently being found at the level of individual rooms. This approach, while better than working in inadequate space, is still not cost-effective. For example, temperature control was improved in one laboratory recently so that single-molecule manipulation could be performed, but the extension of similar capabilities to the other laboratories on a room-by-room basis will require much more than the $500,000 currently available.

JILA's Responsiveness

The subpanel found that, on the whole, JILA had been somewhat responsive to the recommendations made in the previous (2000) assessment report. The subpanel was pleased by JILA's actions in the area of hiring interdisciplinary researchers and on facilities issues but concerned about JILA's lack of action in developing a vision for the institute, putting together a committee to nurture relationships with CU academic departments, and focusing and tracking its industrial interactions.

With respect to the positive actions—in 2000, the subpanel recommended that, as new fellows with research activities in interdisciplinary areas were hired, JILA should develop new partnerships with relevant CU departments. In 2001, a new fellow with biophysics expertise joined JILA, and through him, ties are being formed to molecular biology and applied mathematics faculty on the CU campus. This is a positive step for both JILA and CU, and in future years the subpanel will assess the evolution of these relationships. In 2000, the subpanel also recommended that NIST and CU find ways to improve the quality and quantity of laboratory space. This is a difficult task because of the large amount of money and time required to make a significant difference in facilities, but the subpanel was pleased to see that JILA, NIST, and CU management are making active and creative efforts to address the problem. Some progress has been made, and the subpanel will continue to monitor the situation.

The subpanel was disappointed to learn that there were three recommendations from the 2000 report on which JILA took no action:

1. To develop a strategic vision for the JILA of the future to guide hiring and resource allocation decisions;
2. To appoint a committee to strengthen ties to all the CU departments with which JILA is allied; and
3. To determine what industrial activity at JILA should be, review JILA's track record with meaningful metrics, and put in place a plan for industrial activities that is appropriate to the JILA-NIST mission.

While the subpanel recognizes that the recommended actions can be difficult tasks, it was concerned that no attempts at these actions appear to have been made and that no reason for JILA's lack of action in these areas was provided to the subpanel.

The subpanel was particularly uncomfortable with JILA's lack of action in the first area. The subpanel recognizes that despite the absence of a formal long-range plan, JILA has been able to optimize its course. Nevertheless, strategic thinking has been called for by previous panels and formal strategic planning is currently a focus area within NIST. The 2002 panel was able to obtain a vision statement from JILA management during the assessment, but this is only a beginning: the statement was not reviewed by the JILA fellows, and the strategic ramifications of the statement have not been developed. The lack of progress in the other two areas is also unsettling. Evidence for difficult relations with some CU departments was obvious in 2000, and this has since become a major issue. The casual attitude about coordination of industrial activities is difficult to understand, considering that the NIST mission includes supporting the U.S. economy. Lack of progress in these three areas is unacceptable and should be actively monitored in the reviews by future subpanels.

Major Observations of the Subpanel

The subpanel presents the following major findings and recommendations.

Findings

- The JILA programs, supported by CU and by NIST as well as by government contracts, thrive in an environment of interactive research in which synergies between the fellows are exploited across multiple disciplines. JILA's record of successful identification, appointment, and career development of fellows is a key factor in producing the high-quality research that occurs at JILA.
- JILA is an extraordinary, vibrant institution, thanks to a confluence of several key elements of success, including the partnership between CU and NIST, the synergy between and physical proximity of the researchers, excellent technical support, and adequate and flexible funding. However, some issues, such as resource and infrastructure limitations that may affect retention, pose a challenge to the preservation of all of the elements that contribute to JILA's success. A formal vision for JILA, which could guide critical decisions, has not yet been developed.
- Through creative and exciting research, JILA serves its academic customers with distinction. However, JILA's service to industry continues to be less organized and less effective than is desirable, and JILA has in fact lost ground in developing its industrial connections since the last assessment in 2000. The transfer of discoveries and inventions to the commercial stream for public benefit is one aspect of the mission and responsibility of JILA, but the lack of guidelines on effective technology transfer places fellows at risk when they are faced with the complexities of conflict-of-interest issues in technology transfer and industrial interactions.
- The departure of a senior NIST JILA fellow is an opportunity for growth and evolution, and recruitment of new staff will be facilitated by JILA's current high visibility in the scientific community. However, the strained relationship between JILA and the CU Chemistry Department is constraining JILA's ability to hire new physical chemists, making it very difficult for JILA to make rational decisions about the future direction of physical chemistry at JILA.
- The quality of the physical plant at JILA is not commensurate with the quality of the science, and, though some progress has been made, adequate funds are not currently available to fully remedy this situation. The existence of superb shops and staff have enabled the fellows to do world-class work, but spending time and money on "work-arounds" is not cost-effective.

Recommendations

- NIST and CU should jointly establish a committee to examine the current status of the working relations of JILA with relevant CU departments, including Chemistry; Physics; Astrophysical and Planetary Sciences; and possibly Molecular, Cellular, and Development Biology and Applied Mathematics. The committee should be charged by and report back to both NIST and CU with its findings and recommendations.
- JILA should establish a formal program to support and encourage industrial interactions and should track these interactions. JILA, working jointly with NIST and CU, also needs to establish and formalize policies for technology transfer and best practices in interactions with companies.
- The JILA laboratory needs a comprehensive space and renovation plan. NIST and CU should provide the funding needed to implement such a plan.
- JILA should debate and build on its newly proposed vision in order to develop an overall vision for the future of JILA; this vision should provide a context for critical decisions about hiring and infrastructure improvements that need to be made in the next few years.

6

Materials Science and Engineering Laboratory

PANEL MEMBERS

James Economy, University of Illinois at Urbana-Champaign, *Chair*
David W. Johnson, Jr., Agere Systems (retired), *Vice Chair*
Dawn A. Bonnell, University of Pennsylvania
Karla Y. Carichner, Conexant Systems, Inc.
Michael J. Cima, Massachusetts Institute of Technology
F.W. Gordon Fearon, Dow Corning Corporation
Katharine G. Frase, IBM Microelectronics Division
Elizabeth G. Jacobs, Texas Instruments
Sylvia M. Johnson, NASA-Ames Research Center
Elsa Reichmanis, Bell Laboratories/Lucent Technologies
Lloyd Robeson, Air Products and Chemicals, Inc.
Iwona Turlik, Motorola Advanced Technology Center
Robert L. White, Stanford University
James C. Williams, Ohio State University

Submitted for the panel by its Chair, James Economy, and its Vice Chair, David W. Johnson, Jr., this assessment of the fiscal year 2002 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 14-15, 2002, in Gaithersburg, Md., and documents provided by the laboratory.[1]

[1]Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Ceramics Division: FY2001 Programs and Accomplishments,* NISTIR 6780, National Institute of Standards and Technology, Gaithersburg, Md., September 2001. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Materials Reliability Division: FY2001 Programs and Accomplishments,* NISTIR 6795, National Institute of Standards and Technology, Gaithersburg, Md., September 2001. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Polymers Division: FY2001 Programs and Accomplishments,* NISTIR 6796, National Institute of Standards and Technology, Gaithersburg, Md., September 2001. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Metallurgy Division: FY2001 Programs and Accomplishments,* NISTIR 6797, National Institute of Standards and Technology, Gaithersburg, Md., September 2001.

LABORATORY-LEVEL REVIEW

Technical Merit

The Materials Science and Engineering Laboratory (MSEL) states that its mission is to work with industry, standards bodies, universities, and other government laboratories to improve the nation's measurements and standards infrastructure for materials. The MSEL is organized in four divisions: the Ceramics Division, the Materials Reliability Division, the Polymers Division, and the Metallurgy Division. These four divisions are assessed in the report that follows. MSEL also houses the NIST Center for Neutron Research, which is reviewed in a separate subpanel report at the end of this chapter. The MSEL organization is presented in Figure 6.1.

The MSEL continues to perform work of strong technical merit. In general, the technical competence of staff members is very high, and their projects often push the state of the art and its applications. This strong technical merit is evidenced in part by the awards garnered by MSEL researchers and by the strong publication record that the laboratory has amassed.

The level of accomplishment in the laboratory is quite high relative to similar organizations. The laboratory's output is generally excellent in terms of both quality and quantity. The panel was particularly impressed with the accomplishments achieved relative to the resources available to laboratory researchers.

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

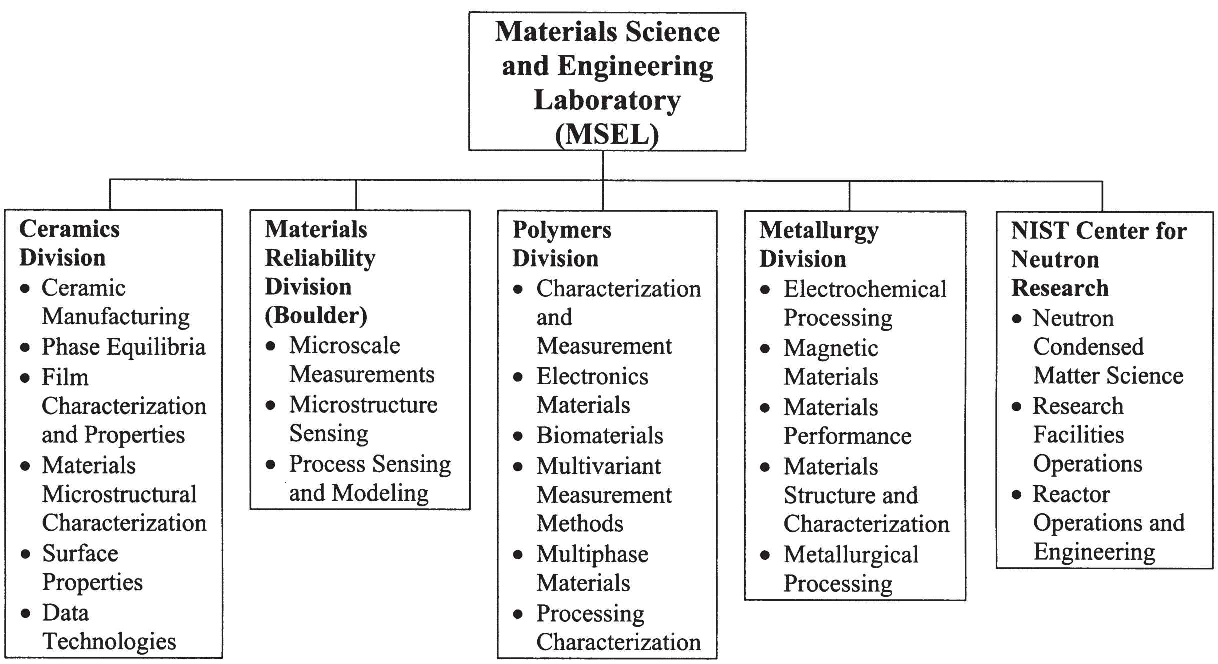

FIGURE 6.1 Organizational structure of the Materials Science and Engineering Laboratory. Listed under each division are the division's groups. Listed for the NIST Center for Neutron Research are the center's three groups.

expertise brought to technical problems and thus increasing the sophistication of experiment and theory applied to their solutions.

Specific examples of programs with particularly strong technical merit are presented in the divisional reports below.

Program Relevance and Effectiveness

Overall, the panel was pleased with the relevance and effectiveness of MSEL's programs. Many examples of programs that have relevance and effectiveness exist, such as these:

- *Phase equilibria studies.* This area of basic research may be quite traditional, but the program goes beyond traditional methods to provide data on properties of materials and systems, which enables industrial researchers to solve important problems relevant to materials processing and product development.
- *Combinatorial methods.* Many researchers and organizations are involved in this "hot" field, which is already used to decrease discovery time in the pharmaceutical industry and is being adapted for many other development uses. However, MSEL has identified an important and appropriate niche in this crowded field, focusing on developing standardized methodologies and measurements so that researchers will ultimately be able to compare results obtained in different laboratories using different protocols.
- *Standard Reference Materials.* Although the production and characterization of SRMs may seem mundane, these artifacts underpin tens of thousands or more measurements in industry each year. They allow researchers throughout the country to assure the precision and accuracy of the measurements that underlie their guarantee of products' performance and safety. The SRMs produced in MSEL are recognized as crucial to technology.
- *NIST-Recommended Practice Guides.* This recently instituted series of instructional booklets provides practical, easy-to-understand advice and guidance on performing standard materials measurements. The booklets are a means of disseminating the experience of NIST scientists, who practice measurement science every day, to researchers throughout the country, who may have recourse to these measurement methods only infrequently. MSEL has been a leader within NIST in publishing these Recommended Practice Guides.
- *WebBooks.* MSEL has initiated the publication of data through these instruments on the World Wide Web. These resources have been quickly utilized by the broad technical community and praised for their utility and impact.

The divisional reports below contain more examples of programs with strong relevance and effectiveness. Although many strong examples of relevant and effective programs exist within the MSEL, there is still room for improvement. Although the laboratory has a strategic plan, it is not clear that all levels of staff understand the laboratory's strategic priorities. Through its discussion with various levels of staff, the panel concluded that more effective communication of laboratory priorities, goals, and objectives is called for throughout the organization. There was a perception among some staff members that the laboratory's stated priorities and goals were simply "buzzwords of the day" and not long-term strategic directions. All levels of laboratory management need to reinforce the importance of laboratory priorities through their actions as well as their words.

Laboratory Resources

Funding sources for the Materials Science and Engineering Laboratory are shown in Table 6.1. As of January 2002, staffing for the laboratory included 162 full-time permanent positions, of which 136 were for technical professionals. There were also 38 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

NIST is finalizing its institutewide strategic plan and has identified several Strategic Focus Areas that can provide important opportunities for MSEL to contribute to national goals. In particular, MSEL has expertise that could contribute strongly to NIST work in the areas of homeland security (nondestructive evaluation of infrastructure) and health care (tissue engineering). However, the panel is concerned that the steady decline in the number of MSEL staff may make the laboratory unable to step up to these challenges and opportunities.

TABLE 6.1 Sources of Funding for the Materials Science and Engineering Laboratory (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	30.6	30.1	31.3	32.0
Competence	0.3	0.1	0.4	0.9
ATP	2.5	2.7	2.6	0.9
Measurement Services (SRM production)	0.9	0.7	1.0	1.0
OA/NFG/CRADA	3.8	3.9	2.8	3.1
Other Reimbursable	0.2	0.6	0.7	0.1
Total[a]	38.3	38.1	38.7	38.0
Full-time permanent staff (total)[b,c]	199	178	163	162

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 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 subpanel review of that facility.

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

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

As the number of permanent staff continues to decline, the panel is concerned that core competencies of the laboratory are increasingly at risk. Important skills and knowledge often reside with only one staff member. Many important staff members are approaching retirement eligibility; mentoring and training of new staff in their skills must occur before these individuals leave. Declining numbers of personnel put the capability to transfer this knowledge at risk. Junior staff at the laboratory report that the presence of a strong cohort of colleagues is a major reason why they have chosen to work at NIST. If staffing levels continue to decline, 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.

MSEL has some very good examples of leveraging its human resources through collaborations. Its program in tissue engineering is a particularly good example. This program involves collaborations with other laboratories at NIST, and with external researchers at other government agencies and in industry. The program consequently has the potential for far greater accomplishment and impact than if MSEL had attempted to enter this area on its own. The panel encourages MSEL to continue the efforts it has made thus far 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 embarked on an important path of providing various means of linking and disseminating data through the Internet. The panel encourages this effort and urges the laboratory to consider strengthening its skill level in information technology (IT) to support these programs.

MSEL has a particular management challenge because its staff is located in both Gaithersburg, Maryland, and Boulder, Colorado. The laboratory has greatly improved coordination between these two sites in the past year through a special budget to encourage staff to travel between the two sites to interact with their colleagues. Not only has this greatly improved collaboration between the Boulder and Gaithersburg staff, but it allows the laboratory to make much better use of the skills resident in Boulder. The panel hopes that resources for such travel will continue to be made available. It also notes that most of the travel in the past year was on the part of Boulder researchers; visits between Boulder and Gaithersburg should be more reciprocal. In particular, Gaithersburg laboratory management could reinforce the importance of staff at Boulder through more frequent visits there.

Facilities for the Boulder researchers have improved somewhat but are still problematic and below standard for laboratory space of this sort. The panel understands that NIST is moving to correct facilities inadequacies at Boulder and will look for progress on this topic.

Responsiveness to Previous Report

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. In almost all cases where specific program focus and direction had been questioned by the panel, the laboratory reexamined its programs and either adjusted the focus or terminated the program. The panel applauds the laboratory on this responsiveness. Continued attention is needed to more general concerns such as communication of goals and objectives to staff and to the potential for subcritical staffing of programs.

[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.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- The Materials Science and Engineering Laboratory continues to field programs of high technical merit and strong relevance and effectiveness.
- Laboratory managers at all levels must reinforce laboratory goals and objectives in both words and action in order to increase understanding of these priorities throughout the laboratory and to improve program focus.
- The panel is concerned that decreasing staff levels put core MSEL competencies at risk and hamper the laboratory's ability to step up to new challenges and priorities.
- MSEL should seek further opportunities to leverage its human resources through appropriate collaborations. The Tissue Engineering Program is an excellent example of such leveraging.
- Increased staff travel between Boulder and Gaithersburg has paid off in better collaborations between the two sites. Funding for such travel should be continued.

DIVISIONAL REVIEWS

Ceramics Division

Technical Merit

The Ceramics Division states its mission as working with industry, standards bodies, academia, and other government agencies in providing leadership for the nation's measurements and standards infrastructure for ceramics materials. The division is now organized in six groups: Ceramic Manufacturing, Phase Equilibria, Film Characterization and Properties, Materials Microstructural Characterization, Surface Properties, and Data Technologies. The panel was presented with detailed updates on six divisional programs: Advanced Engine Materials, Powder Measurements, Advanced Manufacturing Methods, Nanotribology, Phase Equilibria, and X-ray Characterization.

In the past year, the Ceramics Division has made several notable changes to its programs. It successfully completed the realignment of the ceramics machining and ceramics manufacturing activities and the coatings activities into the Powder Measurements Program and the Advanced Engine Materials Program. This change entailed directing resources to select, narrow problems such as specific nanoparticle characterization and reliability of thermal barrier coatings. A new industrial advisory panel on ceramic wear components was constituted for the Advanced Engine Materials Program. This advisory panel includes component suppliers, engine suppliers, and test instrument firms. Other changes include the expansion of efforts in nanotribology, wideband gap materials, and combinatorial chemistry. In addition, a new research effort on low-temperature co-fired ceramics (LTCC) was initiated as the Advanced Manufacturing Methods Program. A number of these changes implemented previous panel recommendations. Finally, owing to a promotion, the division is now planning a nationwide search for a new chief.

The Powder Measurements Program focuses on three topics: measurement and dispersion of nanosize powders, measurements in concentrated systems, and detection and characterization of larger particles or agglomerates. These areas are extremely important for a rather broad cross-section of industry. For example, nanosized-particle media are used for chemical mechanical polishing of wafers at intermediate processing steps in microelectronic manufacturing, and nanosized particulates of pharmaceuticals are increasingly important for the formulation of new drug products. Within the broad research arena, there is a severe lack of metrological rigor and an absence of standards for the characterization of nanoparticulate systems, despite their increasing importance. The division is pursuing three strategic research initiatives to mitigate this technological deficiency. The first is an effort to develop a sub-500-nm-particle-size Standard Reference Material. This material must have well-characterized physical and optical properties, and dispersion protocols must be provided. The second initiative is in situ measurements on slurries of nanoparticles and the detection of defect-causing particles. This research initiative could provide important new process control measurements as well as opening up important new basic science. Regarding the third initiative, a new project to determine the optical constants for nanoparticulates is under study. These constants are required to improve the accuracy of laser-based metrology methods for nanoparticles. Property measurements on nanometer-scale volumes of materials are increasingly important, and the panel believes that NIST should play an important role in developing these techniques.

The Advanced Manufacturing Methods Program consists almost entirely of a process modeling effort for the manufacture of low-temperature co-fired ceramics. LTCC products are primarily used in hybrid packages for electronics. They are assuming an increasingly important role in modules for radio-frequency (RF) technology. Early generations of these packages were simple co-fired structures with Ag/Pd thick-film conductor traces. More recently, LTCC products incorporate co-fired resistors and capacitors. Active devices are added during postfiring assembly operations. In addition to electronics, several experimental approaches to preparing fluidic devices by this method exist, so that complex internal cavities can be produced. Key to all of the existing and potential applications is the ability to predict with precision any dimensional distortion that will occur during sintering. The current industrial practice involves empirical trial tests and repeated retooling. The NIST program seeks to develop predictive tools for these processes and is trying to leverage efforts at other laboratories that use different approaches to predicting the distortion that occurs during the manufacture of these products. The panel had some concern that this particular problem is rather narrowly focused to a small technical need. The microstructure-based modeling approach that is being employed is sound if applied to gross distortions that occur on the hundreds-of-microns scale. Unfortunately, the approach is unlikely to help with the very subtle distortions that occur on a macroscale, such as camber (bending). Many factors other than the local ceramic microstructure contribute to these small distortions on a large scale. It is possible this approach will lead to microstructure-based constitutive parameters and relationships that could be useful for conventional continuum modeling of the sintering process.

Nanotribology is a critical area that directly impacts information storage industries. The division's Nanotribology Program is in a leadership position in the area of magnetic hard disk technology. Recent technical advances achieved by the division include new measurement tools and new understanding of issues involved in molecular interactions in organic lubricating films. These studies have led to a strategy of molecular assembly of more effective organic lubricating films. The panel strongly endorses the division's expansion of this program to include tribology in microelectromechanical devices (MEMs), since wear is a significant impediment to their broader adaptation. This expansion is possible because of an external grant program involving Ohio State University; the University of California, Davis; and the University of California, Berkeley. The panel further encourages strategic hiring to extend the division's internal capabilities in MEMs, an area in which NIST has the potential to make substantial contributions.

The X-ray Characterization Program continues to make outstanding contributions to many NIST research projects. The research carried out at the NIST beam lines at Brookhaven, the Advanced Photon Source, and NIST is of the highest quality. Some recent highlights that directly influence the Ceramics

Division include dopant identification in alumina, the structure of oxide films on GaAs, creep cavitation, and the formation of Stober silica. This program also includes research relevant to programs outside of the Ceramics Division, in areas such as protein crystallography. This research is exploring exciting new directions that extend the NIST competence in x-ray characterization to a broader community.

The Advanced Engine Materials Program combines elements of the former Ceramic Manufacturing and Coatings Programs. “Advanced engine materials” is a very broad area, encompassing monolithic and composite materials and coatings for diesel and gas turbine engines. The program is focusing on two areas: rolling contact fatigue of silicon nitride and thermal and mechanical properties of thermal barrier coatings. The rolling contact fatigue work is aimed at diesel applications, while the thermal barrier coatings work is for gas turbine applications. The program has an Industrial Advisory Panel, consisting of both industrial and academic representatives. The first meeting of this advisory panel in December 2001 resulted in very positive comments on the program, together with the suggestion that a future measurement direction might be thin, wear-resistant films, especially for light alloys. Two NIST fellows are involved in this program, both in the area of rolling contact fatigue and in that of failure mechanisms at intermediate temperatures (700 to 800 °C).

The division’s work on rolling contact fatigue is being guided by an assembly of companies, national laboratories, and universities through a Contact Damage Working Group. This group developed a project plan for studying the standard test methods for rolling contact fatigue, developing models, and developing a practice guide. A series of round-robin tests on the three-ball and cylinder test, a cam follower simulation test, and characterization of diesel engine parts after use are planned. The leader of the working group is also involved with the International Energy Agency in an effort to compare test methods used in Europe, Japan, and the United States. The division faces many practical considerations when designing test methodologies, and it must balance the ease of testing with the usefulness of the data derived from the test. This is particularly true for the three-ball test, which may require better instrumentation to understand the range of applicability of the test. The panel advocates a balanced approach to understanding current rolling contact fatigue testing methodologies and a broadening of the scope of testing approaches.

The thermal barrier coatings work, a continuation of previous work, involves object-oriented finite-element (OOF) simulations, finite element modeling of residual stresses, and the development of a fracture mechanics model. The application of OOF is interesting, as are the variations in microstructure appearing as a result of changing the imaging analysis protocol. Modeling has been done on ideal microstructures and is being extended to real microstructures. The initial results of this effort are promising. This work is performed in collaboration with GE, and, in general, the panel finds this work to be scientifically sound and of interest to the community.

The Phase Equilibria Program has continued its excellent work during the past year. A current focus on dielectric ceramics seeks to measure and predict phase equilibria and electronic behavior in dielectric oxide ceramics, with applications to relaxor ferroelectrics, dielectrics for cellular base stations, and dielectrics for LTCC applications. First-principles computational studies are included in this effort. The particular merit of this program is that it enables the use of phase diagrams to determine material compositions that have specific properties needed for industrially important applications. An example is the need to have materials with high permittivities as well as temperature stability. Development and exploration of a potential phase diagram (MgO-$LaO_{1.5}$-TiO_2-$CaTiO_3$) steered industry away from one research direction and indicated more likely compositional areas. In the study of the Bi-Zn-Nb-O system, the use of phase diagrams and structure refinement contributed significantly to the understanding of the properties of a particular compound. The first-principles effort has made progress, as in the development of an approach to enable $40 \times 40 \times 40$ molecular dynamic calculations. The long-term goal of this effort is to guide experimental work, and the work described by the division is consistent with that goal.

Program Relevance and Effectiveness

The Nanotribology Program is well connected with industry through active involvement in the National Storage Industry Consortium. The relevance of this program to industry is demonstrated by the active participation of industry leaders in the NIST research.

The X-ray Characterization Program has a number of impacts. SRMs for line position and quantitative analysis developed in the program are being utilized at an increased rate, with 50 to 100 percent more sales this year than last. The breadth of impact is also demonstrated in the prolific publications that NIST has had in this area in journals as diverse as *Nature, Physical Review,* and *Macromolecules.* An extensive community that involves more than 100 direct users from more than 50 academic and industrial sites utilizes x-ray beam lines that are supported by NIST. The impact in materials research is much broader than even these numbers indicate. The existence of these facilities and the excellence of the associated staff are a critical asset to the country.

The Advanced Engine Materials Program is exploring areas of industrial relevance and, as mentioned above, has engaged an industrial advisory panel to evaluate the work. The guidance received from the working group in contact fatigue is valuable. The program has identified that existing rolling contact fatigue testing methodologies lack reproducibility and that no basic understanding exists of the relevant phenomena that control the outcome of the tests. This is an important opportunity for future work. The thermal barrier coatings work is of interest, but the program should consider expanding industrial contacts in this area for further guidance.

The Phase Equilibria Program is addressing problems of considerable technical interest. Resulting presentations at technical meetings have resulted in valuable interchange with peers and have aided industry and academia in understanding and developing new materials. The program has also provided one of several excellent opportunities for summer undergraduate research fellowships (SURF) students. Both the productivity of this program and its technical relevance are outstanding. Even the first-principles effort is involved in applications through a working group and workshops. The potential of this basic effort is considerable, and it should be continued.

The Powder Measurements Program has been extremely effective in disseminating results and information during the past year and at gaining direction from industrial collaborators. More than 3,800 hard copies and more than 13,000 Web downloads of the "Particle Size Characterization" Recommended Practice Guide (RPG) were distributed. More than 400 copies of "The Use of Nomenclature in Dispersion Science and Technology" RPG were requested between October 2001 and March 2002. The program's focus group conducted a workshop on nanopowder measurement needs, and attendees included electronic materials suppliers, pharmaceutical companies, instrument manufacturers, national laboratories, armed services laboratories, and universities. The results were used to propose the research agenda for the newly focused program.

Division Resources

Funding sources for the Ceramics Division are shown in Table 6.2. As of January 2002, staffing for the division included 52 full-time permanent positions, of which 44 were for technical professionals. There were also 4 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

TABLE 6.2 Sources of Funding for the Ceramics Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	9.4	9.2	9.6	8.8
Competence	0.0	0.0	0.1	0.1
ATP	0.7	0.8	0.7	0.2
Measurement Services (SRM production)	0.3	0.2	0.2	0.0
OA/NFG/CRADA	1.2	1.5	1.0	0.9
Other Reimbursable	0.1	0.2	0.2	0.1
Total	11.7	11.9	11.8	10.1
Full-time permanent staff (total)[a]	59	57	51	52

NOTE: Sources of funding are as described in the note accompanying Table 6.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

Materials Reliability Division

Technical Merit

The mission of the Materials Reliability Division is to develop and disseminate measurement methods and standards enhancing the quality and reliability of materials and to provide technical leadership in their introduction to the appropriate industries. The division is organized in three groups: Microscale Measurements, Microstructure Sensing, and Process Sensing and Modeling. This division has continued to shift its focus to the electronics industry while maintaining several key infrastructure support efforts. It is also exploring opportunities to apply its unique expertise in new directions, such as health care research.

The Microscale Measurements Group is working on advanced measurements for microelectronic chip and chip package failure modes. The group has made significant advances in areas including quantitative assessment of the role of strain in electromigration failure, establishing standard methods for mechanical testing of thin films, quantifying interfacial thermal resistance in packaging systems, and establishing a high-temperature SRM for thermal coatings.

The Microstructure Sensing Group studies the use of advanced ultrasonics for microelectronic applications. This group continued to develop and apply measurement technology to improve understanding of the properties and performance of materials. Advances were made in the past year in the ability to make quantitative measurements of thin-film mechanical properties using acoustics. A Green's function analysis technique was developed that allows for the measurement of anisotropic film properties. TiN hardness measurements were made and correlated to nanoindentation results. The group has also made progress in using carbon nanotubes as atomic force microscopy cantilever tips for making conductivity measurements.

The Process Sensing and Modeling Group concentrates on developing material measurement technologies and implementing process control. Current projects focus on nondestructive methods for characterizing materials (high-energy x-ray diffraction), research in joining technologies (soldering, welding), and the development of SRMs (Charpy impact testing). This group also plays a significant role in infrastructure support. In FY 2001, the group determined the reason for metallurgical failures at the nation's major dams (Hoover, Big Thompson) and on the WWVB tower. It also provided metallurgical expertise in the inspection of major water-retaining structures and worked on the development of the lead-free solder database.

The Materials Reliability Division is well positioned to establish each of its groups as a worldwide center of excellence. The division houses measurement expertise from the macro- to the nanoscale. The staff covers a broad range of materials and modeling expertise, including microelectronic and photonic materials as well as more traditional structural materials. The division has one of the best bodies of knowledge in the United States with which to address issues associated with national infrastructure.

Program Relevance and Effectiveness

The panel applauds the steps that the Materials Reliability Division took in FY 2001 toward its continuing reorganization. The revised mission statement in FY 2001 is more focused and concise. The panel noted several significant accomplishments that address issues in the microelectronics and telecommunications industries. At the same time, the division has continued to work on projects of great importance to the nation's infrastructure. Now, the division has made a very successful start at applying its expertise to issues in health care. Clearly, the division has a unique combination of people, expertise, and experience to apply to issues of vital importance to the nation.

However, the Materials Reliability Division has limited opportunity to cover such a wide spectrum of topics in depth. With such distinct areas of expertise, the division might be more effective if it organized into centers of excellence reflecting its core expertise. As it establishes such centers of excellence, the division might consider names that better reflect these core competencies. This might ensure that the group structures continue to be relevant to national priorities from year to year. Another beneficial short-term activity for the division might be strategic planning that would enable it to maintain critical support for traditional industries, infrastructure, and standards and yet also be a leader in new areas of materials reliability.

Projects addressing issues in the semiconductor, computing, and telecommunications industries continue to have significant relevance. For example, the division's work on developing standards for testing of thin films, progress in quantitatively assessing damage mechanisms with microelectronic interconnects, and using carbon nanotube tips in atomic force microscopy all address the need for strong measurement techniques and standards in these industries.

The Materials Reliability Division also continues as the main source for materials information on issues integral to the nation's infrastructure support. Several examples include work on Charpy impact verification, welding, forensic analysis, and the lead-free solder database. In a number of efforts, the division is a sole source of support (e.g., structural integrity of major pipelines) and has an expertise that cannot be easily duplicated if lost. This places the division in a unique position to address issues vital to homeland security.

As a center of excellence for materials reliability, the division is continually engaged in determining how it can best apply its expertise to problems of national strategic importance. Continuous feedback from customers and input from potential customers might help in setting priorities and add to recognition of the division as a national leader in materials reliability. Although the division has done well in participating in industry consortia on certain topics, it has had very limited success in executing cooperative research and development agreements (CRADAs) with industry partners, partly because of difficulty in executing nondisclosure agreements between NIST and individual industry partners. The division's use of conference attendance with presentations and NIST-sponsored workshops to obtain feedback has yielded information that can be used to impact division programs directly. Another way to strengthen information gathering is to consult experts in business, finance, and venture capital firms in order to obtain insight into industry trends, emerging technologies, and technology gaps.

The panel strongly endorses the approach that the division has taken in determining a best fit for its expertise in the area of health care. Consulting with an expert from academia who has a wealth of knowledge and a strong network in the industry is an excellent start to identifying the right niche for the division's expertise. This effort has already led to contacts at the Children's Hospital in Denver and to potential research collaboration. The panel recommends that the division also look to colleagues in Gaithersburg and at other government agencies who can provide additional insights and introductions to appropriate contacts.

In its current programs, the division has a number of customers and collaborators on various projects. These partners include academia, national laboratories, and industry collaborators. The results on Charpy impact verification and metallurgical failure analyses (pipeline, dams, WWVB tower) are disseminated directly to customers for immediate use. In other cases, information is disseminated to customers primarily through participation in consortia, technical publications, and conference presentations, so direct use is harder to gauge.

Division Resources

Funding sources for the Materials Reliability Division, shown in Table 6.3, remained flat for FY 2001 and FY 2002. As of January 2002, approximately 4 months into FY 2002, the division was still unable to finalize its budget because internal funds for key proposals had not been finalized or allocated.

TABLE 6.3 Sources of Funding for the Materials Reliability Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	4.1	4.1	3.8	4.0
ATP	0.3	0.4	0.4	0.3
Measurement Services (SRM production)	0.4	0.2	0.5	0.9
OA/NFG/CRADA	0.4	0.2	0.1	0.2
Other Reimbursable	0.0	0.2	0.2	0.0
Total	5.2	5.1	5.1	5.4
Full-time permanent staff (total)[a]	29	19	20	19

NOTE: Sources of funding are as described in the note accompanying Table 6.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

Some allocations in FY 2001 that were awarded late in the fiscal year probably affected programs because of the shortened timeframe.

As of January 2002, staffing for the Materials Reliability Division included 19 full-time permanent positions, of which 17 were for technical professionals. There were also 2 nonpermanent and supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The division staff continues to demonstrate the high quality of its personnel and a high level of output. The staff produced 75 publications and 3 new patents in 2001. However, the staff is spread thinly over the projects it supports and without additional staffing will not be able to take on new projects such as health care research.

The division is successfully recruiting and retaining its personnel. In FY 2001, the division promoted two staff members to leadership roles as group leaders. The panel was impressed with these selections. They are a positive start toward addressing the critical need for succession planning in the division. In addition, the division was able to retain a retiring senior staff member on a contractual basis. This was a very creative way of retaining senior expertise, and the panel applauds the changes that were made in the requirements for retaining retiring employees in order to secure this expertise. Several new employees were added to the technical staff in FY 2001, although none are permanent staff. The panel suggests increasing the use of a formal search committee at the MSEL level to recruit top senior talent. The panel further recommends that NIST also look for novel ways to recruit senior staff. One suggestion is to recruit from the growing population of early retirees or technical professionals from key technical industries. Contacts to outplacement firms and job postings in industry trade and professional organization publications are ways to reach this population.

Resources allocated for staff travel between Gaithersburg and Boulder continued to show positive results on programs in FY 2001. The Microstructure Sensing Group was able to collaborate on an Advanced Technology Program project with the Polymers and Ceramics Divisions. The Process Sensing and Modeling Group successfully collaborated with the Metallurgy Division on steels and solders. The Materials Reliability Division is continuing this positive trend by starting collaborations with the Polymers Division in the new health care thrust. In addition, there has been an increase in travel from Boulder to Gaithersburg for training and other presentations. To further enhance collaborations and to fully establish the synergy between collaborating groups, the panel believes that the face-to-face interchange must occur in laboratories on both campuses. It is also important for the Boulder team to expand its interaction with the Gaithersburg senior management team. The panel strongly recommends that the senior staff of MSEL Gaithersburg further increase its participation in Boulder activities.

The panel finds that the division has managed its capital equipment planning well. The division has done a good job of prioritizing to realize immediate program goals while staying within the capital equipment budget. However, the panel believes that more focus should be given to the strategy for future and long-term capital investments. The division should develop a critical, "must-have" list of the capital equipment needed to maintain the division's status as a worldwide center of excellence in materials reliability. These capital investments will likely require larger investments than the typical allocation in a 1-year budget cycle.

Polymers Division

Technical Merit

The stated mission of the Polymers Division is to provide the measurement methods, standards, and concepts to facilitate technology development, manufacture of products, commerce, and use of synthetic polymers. The breadth of this mission statement is consistent with the diversity of the industries that the division serves. This division has carefully selected its research presence in the most critical areas in order to have maximum impact on relevant polymer industries. The division has been reorganized to address industry needs effectively. The division has six groups: Characterization and Measurement, Electronics Materials, Biomaterials, Multiphase Materials, Processing Characterization, and Multivariant Measurement Methods.

The Polymers Division has been instrumental in establishing a project-planning protocol to ensure the coupling of new programs and initiatives to the MSEL mission. It has effectively established new initiatives related to tissue engineering, imaging, and combinatorial methods development, all of which have significant potential to impact the U.S. commercial sector through standards and measurement methodology development. In addition to working with the industrial sector, the division is also leveraging its resources through interactions with other laboratories, in particular, with the National Institutes of Health (NIH). Such collaborations are of growing importance as we move into an era of significant innovative discoveries at the interfaces between disciplines. The "future directions" as envisioned by the division's leadership include utilizing the core competencies of the laboratory to expand the biomaterials effort, develop measurement methodologies to better characterize nanocomposites, and develop polymer materials-based process characterization techniques. The panel supports efforts to identify how the division could impact homeland security issues within the scope of the mission and expertise of the group. In particular, the panel thinks that the efforts of the Multivariant Measurement Methods Group (i.e., the NIST Combinatorial Methods Center) could provide a foundation to impact this critical area.

The Characterization and Measurement Group continues to effectively produce the wide range of SRMs needed for the research, development, and commerce of polymeric materials, while also developing and improving test methods for characterizing the molecular structure and properties of these materials. During the past year, this group issued new SRMs for nonlinear viscoelastic properties, recertified melt flow-rate polyethylene standards, produced cubes of ultrahigh-molecular-weight polyethylene reference materials for radiation studies, initiated reference data acquisition for intra-ocular lens biomaterials, and also issued the first molecular mass polymer standards with ancillary mass spectral data. This group, one of the world leaders in the application of mass spectroscopy to the characterization of macromolecules, is making excellent progress toward establishing matrix-assisted laser desorption ionization time-of-flight mass spectroscopy (MALDI MS) as the method of choice for determination of the absolute molecular mass of a polymer. Key to this technique is the production of a stable macromolecular ion, an especially difficult task with saturated polymer systems such as the polyolefins. In a previous review the panel encouraged the Characterization and Measurement Group to pursue solutions to this historic problem. In response, the group has demonstrated an innovative approach in which an organic cation is covalently bonded to the polymer to produce the critical macromolecular ion. The scope of this approach is being established, but all indications to date are that it will form the basis for a new method to characterize the mass and structure of macromolecules. The group is extending its capabilities in optical coherence tomography (OCT). A new confocal OCT configuration permits improved lateral and axial resolution. Improved approaches to polarization detection and to the imaging of chemical functionality are also being developed. OCT is proving to be a rapid method for imaging the structure, function, and dynamics of polymer systems from the nano- to mesoscales. Two focus applications are (1) the quantitative characterization of tissue engineering scaffold microstructure and cell functionality in collaboration with the Biomaterials Group, and (2) the quantitative imaging of damage initiation and propagation in composites in collaboration with the Multiphase Materials Group.

The Multivariant Measurement Methods Group project is a relatively new thrust in the Polymers Division, offering an excellent fit with the mission of MSEL and NIST. Combinatorial methodology is well established in the area of chemical synthesis (e.g., in the pharmaceutical industry). The Polymers Division has been a leader in adapting this approach to methods development relevant to materials science. This year the group has demonstrated the utility of combinatorial testing of polymer adhesion to various substrates. The extension of this work to the rapid evaluation of the industrially important pressure-sensitive adhesive market can be envisioned. Adaptation of this approach to measure thin-film crystallization has been demonstrated, and the method can be extended to nucleation additive evaluation, surface effects on crystallization kinetics, solvent effects, and other environmental effects. Block copolymer self-assembly and the novel morphologies accessible with processing variables have been demonstrated using combinatorial approaches. These methodologies should have relevance to biomaterials, and work has been initiated in the division to explore projects that can merge the two key projects in the Polymers Division. The panel is pleased with the progress of this project and with the response to the recommendations made in last year's assessment.

The Biomaterials Group has effectively broadened its mission beyond its traditional emphasis on dental materials to encompass the development of methods, standards, and fundamental scientific understanding at the interface between materials science and biological science for application in health care. These efforts respond to previous years' recommendations. The group proposes to leverage its expertise in restoration materials to focus on both the dental and medical sectors that apply synthetic materials for replacement, restoration, and regeneration of damaged or diseased tissue. The focus is principally on dental materials, tissue engineering scaffolds, and metrology for tissue engineering. The dental materials effort is conducted in collaboration with the American Dental Association Health Foundation researchers. Notable accomplishments relate to improvements in calcium phosphate cement that can be used to correct bone defects; the use of polylactic/polyglycolic acid (PLGA) microspheres to induce microporosity; and the incorporation of controlled-release bone growth factor and cell seeding of the cement by alginate encapsulation of osteoblasts. These activities lay the foundation for a project focused on the characterization and modeling of tissue engineering scaffolds. The effort is directed at the development of well-controlled model systems and methods to characterize the structure and function of three-dimensional scaffolds. The materials-related efforts have additionally provided systems for the confocal OCT imaging development efforts and have provided a common scaffold materials platform for NIH and the Armed Forces Laboratory of Applied Pathology (AFLAP) collaborators. Most notably, NIST Competence Development funding was received for the Metrology for Tissue Engineering project developed in collaboration with the CSTL Biotechnology Division. This ambitious project has the goal of developing methods that will comprise a measurement system for assessing cell-biomaterial interactions. In addition, the collaboration extends beyond NIST to include NIH researchers. MSEL management should encourage this multidisciplinary, multilaboratory approach to addressing significant problems. It provides for effective leveraging of resources and knowledge and promotes discussion that will stimulate innovation.

The Electronics Materials Group continues to focus on three key areas: the characterization of porous thin-film dielectrics, polymers for photolithography, and permittivity of polymer thin films at microwave frequencies. These efforts are well aligned with defined needs of the U.S. electronics industry as they relate to materials measurement and standards. Significant advancements were seen in the x-ray porosimetry and neutron contrast matching techniques for determination of the structure of nanoporous thin-film dielectrics. The former has the potential of being adapted by industrial laboratories, and the panel encourages those efforts. Within the scope of lithographic materials, the group is applying its expertise in measurements and standards to achieve nanometer-scale resolution to identify both materials and attributes that lead to developed image imperfections such as line-edge roughness in sub-100-nm lithographic patterns. The extent of line-edge roughness has significant impact on critical-dimension control of feature size, which in turn impacts device performance. With respect to permittivity, good progress was made in the use of the new high-frequency broadband dielectric test method as a standard for thin-film dielectrics. A prototype fixture is being manufactured and will be distributed for round-robin evaluations.

The Multiphase Materials Group has historically made significant contributions in the characterization of polymer blends. While this continues at a reduced level, a new focus on nanoparticle modification of polymers and fiber-reinforced composites has emerged. The polymer-blend characterization effort was directed toward metallocene polyolefin blends. The small-angle neutron scattering facility at NIST provides an important and unique tool for phase behavior studies of polymer blends, and significant progress was made this year in polyolefin blend characterization. The Nanocomposite project investigated the structure and alignment of aqueous suspensions of carbon nanotubes in poly(ethylene-oxide) solutions. Additional nanocomposite studies included shear orientation characterization of polymers and nanoclays and a molecular dynamics simulation of nanoparticle clustering in polymer melts. Adaptation of the OOF analysis method developed at NIST was shown to offer promise in determining macroscopic properties from microscale topology in these systems. Multifiber-reinforced composite testing has been developed, and results demonstrate nucleation of failure modes that cannot be seen in single-fiber testing.

The characterization efforts in the Processing Characterization Group are focused in the areas of visualization and development of in situ probes. Dielectric spectroscopy to monitor polymer processing has demonstrated the ability to assess intercalation of polymers in layered inorganic (clay) structures. Studies on processing instabilities in metallocene polyolefins revealed that microcavitation is an important factor in melt fracture during polymer processing. Microscale processing studies are being conducted in response to emerging interest in MEMs devices, microfluidics, and micromanufacturing technologies. The group demonstrated that the microscale processing of polymer emulsions can yield structural changes influenced by shear rate and mass ratio.

Program Relevance and Effectiveness

Overall, the Polymers Division portfolio strikes an appropriate balance between the discovery and development of methods to characterize macromolecules and the application of these capabilities to the development of new technologies. Competencies are being effectively leveraged by collaborations both with other groups, with groups in other divisions, and with leading companies in key growth industries, especially biomaterials and electronics.

The Characterization and Measurement Group meets a key element of the mission of NIST by producing and supplying a wide range of SRMs needed for the research, development, and commerce of polymeric materials. Molecular mass determination by mass spectroscopy offers the promise of rapid absolute molecular mass determination and the elucidation of polymer structure, a capability that is sorely needed for the continued commercial development and application of a wide variety of polymer systems. The group is making excellent progress toward this goal. The optical coherence tomography capability developed over the past several years is being effectively applied in both the biomaterials and composite fields.

The Polymers Division has led in the development of multivariant measurements methods by initiating a Gordon Conference on the topic and forming the NIST Combinatorial Methods Center. Industry is quite interested in combinatorial technology as applied to high-throughput testing and screening for adhesives, coatings, catalyst evaluation, crystallization enhancement, property changes due to environmental conditions, flammability, and general multicomponent formulation evaluation for optimization of properties desired for commercial utility. Areas of potential economic growth are awaiting development of novel rapid testing and screening techniques. Advances in biotechnology, nanotechnology, electronics, and optoelectronics will depend on the successful development of this technology. The combinatorial testing approach should have significant relevance to biomaterials and tissue engineering projects in the Polymers Division; the panel recommends close collaboration with relevant players on these projects. Cell adhesion, scaffold evaluation, bone growth, and cell growth on artificial surfaces are a few of the areas in which this division can deliver needed technology to the health care industry.

The Biomaterials Group has extended its activities to encompass growing needs related to the broad area of health care. It has done so by leveraging its traditional expertise to move into the area of tissue engineering. These activities are utilizing collaborations with other NIST laboratories and NIH, which is likely to enhance the group's effectiveness and long-term impact.

Each of the projects described by the Electronics Materials Group is closely aligned with significant industry needs. The projects effectively utilize the group's expertise in measurement and standards technology and provide significant value to the industry. Within this area, much of the focus has been placed on issues identified by the Semiconductor Industry Association and SEMATECH road maps. While these road maps identify important industrywide issues, they are by nature short term. This group should try to identify generic issues of interest to the electronics industry that can be addressed with its expertise. For instance, the panel suggests exploring opportunities that may arise in evolving areas such as polymers for optoelectronics and plastic electronics. While these currently could be classified as areas of emerging interest, it is anticipated that their importance in the commercial sector will show substantial growth in the future.

The areas of nanocomposites and nanotechnology being addressed by the Multiphase Materials Group are key thrust areas of many academic and industrial laboratories. Proper characterization of the potential of nanoparticle modification of polymers is necessary to separate hype from reality for these technologies. The characterization and measurement technology available at NIST (e.g., SANS) can be very useful for this purpose. Nanoparticle dispersion, particle and polymer interactions, viscosity of nanocomposites, and determination of level of intercalation and exfoliation are several areas in which the Polymers Division has capabilities. The panel encourages the division to move into these areas in order to address such questions. The group's successful project on characterization and modeling of failure in fiber composites needs to be integrated with other composite-failure research programs in the government (e.g., NASA; Air Force Research Laboratory) so that this important work is not conducted in a vacuum. As discussed during the review, work related to more traditional polymer blends should be deemphasized in favor of emerging nanotechnology initiatives.

The Polymer Processing Characterization Group has developed techniques for nanocomposite characterization during processing that are quite important to this emerging area. Its work in microscale processing has relevance to microfluidics, MEMs devices, and microscale analysis and detection systems, and the panel encourages further efforts in this direction. Programs related to conventional polymer extrusion have less apparent impact and should be deemphasized.

Comments on Homeland Security

A national priority in homeland security involves technology development directed at improving testing, detection, and evaluation of potential threats from terrorist sources. The panel discussed possible areas in which the Polymers Division could use its unique skills to contribute to this national interest. The Multivariant Measurement Methods Program has the goal of developing rapid testing and screening technology for microscale quantities of materials. Such methodologies may be relevant to the

TABLE 6.4 Sources of Funding for the Polymers Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	7.5	7.5	7.9	7.6
Competence	0.1	0.1	0.3	0.8
ATP	0.8	0.9	0.8	0.1
Measurement Services (SRM production)	0.1	0.1	0.2	0.1
OA/NFG/CRADA	0.8	0.8	0.9	1.4
Other Reimbursable	0.0	0.1	0.1	0.0
Total	9.3	9.5	10.2	10.0
Full-time permanent staff (total)[a]	45	43	37	37

NOTE: Sources of funding are as described in the note accompanying Table 6.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

rapid testing of air and water sources, determination of chemical or biological contamination, and detection of foreign species (e.g., explosives). Other areas that could be relevant include microfluidics and micromanufacturing for the design of microscale testing devices, testing of fiber-reinforced composites (for lightweight armor; analysis of aircraft component failure), and the electronics materials effort in advancing the testing and characterization of materials for electronic sensors.

Division Resources

Funding sources for the Polymers Division are shown in Table 6.4. As of January 2002, staffing for the division included 37 full-time permanent positions, of which 32 were for technical professionals. There were also 18 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The Polymers Division has successfully recruited increasing numbers of high-quality postdoctoral associates through the National Research Council's postdoctoral program. Several of the NRC postdoctoral associates have been hired into permanent positions, and it is the division's intention to use this program as a pipeline for future high-quality hiring. The skill and quality of the professional and support staff are adequate for the stated mission and targeted programs of the division.

Metallurgy Division

Technical Merit

The Metallurgy Division's stated mission is to provide critical leadership in the development of measurement methods, standards, and fundamental understanding of materials behavior needed by U.S. materials producers and users to become or remain competitive in the changing global marketplace.

This mission is consistent with the overall mission of MSEL and of NIST, and it augments those mission statements by specifically highlighting the importance of critical scientific investigation as the underpinning to developing pertinent and effective standards and measurements.

The Metallurgy Division is organized in five groups: Electrochemical Processing, Magnetic Materials, Materials Performance, Materials Structure and Characterization, and Metallurgical Processing. Each of these groups includes permanent staff, postdoctoral fellows, and guest researchers. As discussed below, the number of division permanent staff is constrained, and the use of nonpermanent colleagues provides both flexibility and critical mass for taking on new programs.

The panel directly reviewed certain programs in each of the groups, while relying on the division's annual report and management discussions for others. On the whole, the reviewed projects were technically sound and in several cases demonstrated significant leadership. The copper plating project, which was highlighted last year for commendation, again delivered industry-leading results, with broad implications for measurement and process improvement for the industry in the future. This work also received the Commerce Department Gold Medal in 2001.

The Metallurgy Division has provided leadership in the area of phase-diagram calculation and data integrity for many years. This phase-diagram expertise, combinatorial methods for sample preparation, and thermodynamic calculations of diffusion are now being applied to GaN low-resistance contacts of importance to the display and optoelectronics industry, and to superalloy processing. The division is also applying detailed microstructural evaluation of samples to ensure that the combinatorial methods result in production of the intended samples. Bringing these disparate skills and techniques together promises to enable significant contributions in 2002.

In 2001, the panel expressed concerns about the technical focus of the Lightweight Metal Forming project. This project has since been reorganized in terms of goals, objectives, and individual assignments. The new team has delivered results translating to some real insights into the stress states and microstructural development of formed aluminum and appears to be on a path for solid technical achievement on an important topic.

The division has for many years delivered leadership science, measurement, and standards in magnetics. Individual programs in magnetics, particularly the Giant Magnetoresistance and Modeling Program, continue to have strong technical merit. However, some of the current projects, while elegant, are not novel. In addition, the panel was concerned that some projects are not focused on the issues of most importance to industry and that the collaboration between Gaithersburg and Boulder on magnetics could be strengthened. The panel recommends that the overall magnetics program be reviewed in terms of programmatic focus and objectives.

Program Relevance and Effectiveness

In order to best use its skills and resources, the Metallurgy Division evaluates each new program proposal in terms of synergy with existing programs, skills, and the division mission; relevance to the perceived customer set; and the ability of NIST resources to make a significant and timely impact. This review ensures that the division is able to provide a significant, focused contribution to the field. The division management also regularly evaluates the full program portfolio to ensure the best use of resources, to maximize technical impact, and to set plans for future hiring or tooling requirements.

Each of the projects reviewed had clearly articulated interactions with the specific customers, as well as plans for data dissemination and measurement of customer feedback. In general, this management system is effectively selecting programs relevant to the primary customer groups (the makers and users of metals for consumer, computer, automotive, and aerospace applications). However, it appears that each project has a fairly narrow constituency and no natural procedure for changing or enlarging constituencies. For example, research on lightweight metal forming has been, is, and is likely to continue to be focused on the auto industry. Similarly, the magnetics effort is focused on magnetic recording, perhaps the dominant but not the only magnetics technology, and one that is itself approaching maturity.

How the Metallurgy Division becomes aware of new areas of need is unclear. The present strategy seems to be to hire talented people, ask them to look around, and then decide what programs, compatible with their expertise, to undertake. Actually that strategy seems to work fairly well, but it requires new staff and has the potential for built-in stagnation if the permanent staff is contracting. The management might request that existing staff perform periodic examinations of the business or technical world with the objective of identifying emerging areas of importance and need.

In several cases, project results (data, software, methods) have been posted directly to NIST or to industry Web sites, and the Web site traffic indicates the use of the data by appropriate customer groups. In other cases, publications and presentations have been targeted to the media most used by a particular constituency, for example to trade journals or conferences. The phase-diagram data on the Web site has been well utilized. The results from the superalloy reaction path testing have been posted and used by the partner companies. The division had hoped by now to have its mechanical properties database online as well, but it is testing alternate data formats to ensure the maximum utility for users before posting.

Division Resources

Funding sources for the Metallurgy Division are shown in Table 6.5. As of January 2002, staffing for the division included 39 full-time permanent positions, of which 35 were for technical professionals. There were also 14 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

TABLE 6.5 Sources of Funding for the Metallurgy Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	7.9	7.5	7.8	7.9
Competence	0.2	0.0	0.0	0.0
ATP	0.7	0.6	0.6	0.3
Measurement Services (SRM production)	0.1	0.2	0.1	0.0
OA/NFG/CRADA	1.2	0.9	0.5	0.6
Other Reimbursable	0.1	0.1	0.2	0.0
Total	10.2	9.3	9.2	8.8
Full-time permanent staff (total)[a]	50	42	38	39

NOTE: Sources of funding are as described in the note accompanying Table 6.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

Over the past several years, attrition in the division has been primarily driven by retirements, performance issues, or contract/funding reductions rather than by resignations. The division has continued to successfully attract new talent to the postdoctoral fellows and guest scientist programs. Its budget continues to decline slightly each year in absolute dollars; when adjusted for pay raises and other expense increases, real purchasing power declines more steeply. To date, the division has managed its expenses and its use of temporary workers in a way that maintains its vitality and its core competencies, rather than diluting its efforts with many outside agency contracts. However, both the management team and the scientific staff expressed concerns that the funding may be reaching a level where this approach will not be adequate. While outside agency contracts can solve funding issues, it is often at the cost of the dilution of efforts on mission-driven projects.

Morale in the Metallurgy Division continues to be very high. The review panel spent time individually with the management team and technical staff with 5 to 15 years' experience, and both groups were positive about the overall atmosphere, the ability to do leadership science, the freedom to select the best projects for their skills and interests, and the management system. Although the division recently lost a promising postdoctoral prospect to a DOE laboratory where salaries are higher and equipment newer, it appears that the external economy itself is having minimal impact on attraction or retention of key skills.

Financial constraints do affect the types of projects that the Metallurgy Division can undertake. The management team has done an excellent job of using this constraint as a motivator to ensure that each program has focus and relevance and to ensure that the portfolio of projects is optimized. However, if the annual attrition trend and pressure to reduce permanent staff continue, there is a very real risk that the permanent staff will become too small or too narrow to sustain the division's important mission and role.

REVIEW OF THE NIST CENTER FOR NEUTRON RESEARCH

This annual assessment of the activities of the NIST Center for Neutron Research (NCNR), part of the NIST Materials Science and Engineering Laboratory, is performed by the Subpanel for the NIST Center for Neutron Research. The report is based on a formal meeting of the subpanel on March 5-6, 2002, in Gaithersburg, Maryland, and on documents provided by the NCNR.[3]

The members of the subpanel were Eric W. Kaler, University of Delaware, *Chair*; Zachary Fisk, Florida State University; Charlotte K. Lowe-Ma, Ford Research Laboratories; Lee Magid, University of Tennessee; Philip A. Pincus, University of California, Santa Barbara; and David C. Rorer, Brookhaven National Laboratory (retired).

Technical Merit

According to NCNR documentation, the mission of the NCNR is to operate the NIST Research Reactor cost-effectively while assuring the safety of the staff and general public; to develop neutron measurement methods, to develop new applications of these methods, and to apply them to problems of national interest; and to operate the research facilities of the NCNR as a national facility, serving researchers from industry, university, and government.

[3]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *NIST Center for Neutron Research: 2001 Accomplishments and Opportunities,* NIST SP 977, National Institute of Standards and Technology, Gaithersburg, Md., March 2002.

The subpanel 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 NCNR are among the best in the world, and the research occurring on these instruments is influential in a number of scientific fields. NCNR is a facility of substantial national importance.

Now and in the immediate future, 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, staff at the NCNR are already actively planning how their facility can complement the SNS 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 experimental approaches that could benefit more from NCNR's steady neutron source than from the pulsed source at SNS.

Decisions about facility improvement at NCNR also take into account many additional factors. For example, staff recognize that experiments using synchrotron sources play an important role in many of the scientific fields under investigation at NCNR. External input is sought from a number of sources, such as the federal-government-wide Interagency Working Group on Neutron Scattering (organized by the Office of Science and Technology Policy); the NCNR Users Group and its Program Advisory Committee; and National Research Council publications, such as this subpanel's annual assessment and the 1999 NRC report on managing the nation's multidisciplinary user facilities.[4] The subpanel commends the NCNR staff's awareness of the overall context in which neutron research occurs and the constant evolution of the field. 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 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 NCNR and will have been trained at the facility.

The NCNR is divided into three groups: Neutron Condensed Matter Science, Research Facilities Operations, and Reactor Operations and Engineering. 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. The teams are Macromolecular and Microstructure Science, Surface and Interfacial Science, Crystallography and Diffraction Applications, Chemical Physics, and Condensed Matter Physics. The NCNR also has a growing effort in life sciences. The work of the five teams and life sciences activities are discussed in the subsections that follow. The Research Facilities Operations Group and the Reactor Operations and Engineering Group ensure 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 titled "Reactor Operations and Research Facilities." Overall, NCNR scientists' strong, collaborative relationships with instrument users maximize not only the efficiency and effectiveness of the work done but also the quality of the results produced on the NCNR instruments.

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[4]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.

Macromolecular and Microstructure Science

The Macromolecular and Microstructure Science Team carries out a research program of high quality that develops and applies neutron methods to the relationship of submicron structures to bulk properties, function, and processing. Staff in this team undertake intramural research, collaborate with scientists and engineers in other NIST laboratories, and collaborate with the users of the four instruments for which this team is responsible (three small-angle neutron scattering (SANS) instruments and one ultrasmall-angle neutron scattering (USANS) instrument). Scientific highlights from this team during the past year include the discovery using SANS and dynamic light scattering of large hydrogen/deuterium (H/D) isotope effects and polymer-polymer aggregation in aqueous solutions of polyethylene oxide (PEO). Hydrogen-bonding interactions were found to be stronger between dPEO molecules than between hPEO molecules; the average-contrast condition, which involves mixed dPEO and hPEO in H_2O/D_2O solvent, thus cannot be used to obtain single-chain conformations in solution. If this result proves to be generally true for aqueous systems, it will have far-reaching implications for the use of contrast variation techniques. In another project, a collaboration with university researchers, it was demonstrated that pressure can be used to induce surfactant microstructures of potential use for templating nanostructured materials. In a third project, another collaboration, the first SANS measurements of the in-flame nucleation and growth of soot particles were made; this set of experiments is reminiscent of earlier work on nucleation and growth of two-component aerosol particles. This project took advantage of one of the many strengths of the NCNR SANS instruments, namely, the ability to mount extensive ancillary equipment for in situ studies. A fourth highlight was the characterization of a novel, ribbonlike phase of mixed lipids which aligned in a magnetic field when doped with a rare-earth cation.

The Macromolecular and Microstructure Science Team provides the staff support for NCNR's two 30-m SANS instruments; the 8-m SANS currently undergoing upgrade, reconstruction, and conversion to a 9-m SANS; and the (still relatively new) USANS instrument. A number of improvements to these instruments were made over the past year. A new optical filter was installed on the 30-m SANS at neutron guide 3 (NG-3), replacing the cooled beryllium/bismuth crystal filters and providing gains in neutron flux by up to a factor of 2.5 at long wavelengths. Focusing biconcave lenses, which are already in routine operation on the 30-m SANS at NG-7, were installed on the 30-m SANS at NG-3, thus providing even greater gains in neutron flux at long wavelengths. Cabling and electronics were refurbished on the 30-m SANS at NG-7, and a new, position-sensitive detector with fast electronics was installed on the 8-m SANS. A new data system for all of the SANS instruments is under development; it will be based on networked communication with the fast detector electronics. New channel-cut crystals were installed on the USANS, removing the possibility of beam contamination by single internal or back face reflection and resulting in a doubling in beam current at the sample with no impact on the signal-to-noise ratio. Improvements are ongoing on the SANS data reduction and analysis software (which utilizes a commercial product called IGOR Pro); particularly notable is the addition of tools for USANS data.

The Macromolecular and Microstructure Science Team has ambitious plans for the future with respect to both science and instrumentation. It is increasing complementary use of SANS and USANS in order to cover a broad range of length scales in hierarchical structures. In response to the polymers and complex fluids communities, the group will enhance the use of in situ rheology with SANS. An optical filter is scheduled to be installed for the 30-m SANS at NG-7, and submillisecond time-resolved SANS will be implemented through installation of a high-speed double-disk counter-rotating chopper for the incident beam.

Surface and Interfacial Science

The Surface and Interfacial Science Team is engaged in a range of high-quality research activity and provides support for NCNR's state-of-the-art reflectivity instruments. Many of this team's scientific problems overlap with the interests of the Macromolecular and Microstructure Science Team and feed directly into the growing activity around biological structure characterization.

An excellent example of the use of reflectivity for the development of new materials of great practical importance is its application to probing the structure of films of low dielectric constant. Such films have severe design constraints, and current efforts are directed toward producing silica-like materials with a high degree of porosity. Design and manufacture therefore require a detailed measurement of the porosity of a thin film, and neutron reflectivity with contrast variation allows such a detailed look at the evolution of porosity in situ during the curing process. Another example in which the ability to examine a film in situ plays a role is the study of the kinetic and equilibrium properties of surfactants adsorbed to surfaces. Such adsorbed layers are critical to many processes, but the assembly of surfactants at an electrified interface has not been well studied. Recently, reflectivity measurements have been combined with in situ electrochemical measurements to study this problem, and the results provide new insights into surfactant rearrangement of such surfaces.

A myriad of other unique materials characterizations have been developed by this group using neutron reflectometry. In particular, the method of polarized neutron reflectivity has been used to extract the structure of buried magnetic spirals in magnetic films. This technique is particularly sensitive to the presence of magnetic twists, and it is possible that better understanding of such twists will provide new routes to the development of magnetic thin-film devices. These and the other advances described above are clear evidence that the Surface and Interfacial Science Team is a well-functioning scientific team working at the forefront of its scientific field.

Crystallography and Diffraction Applications

In crystallography, the Crystallography and Diffraction Applications Team has responsibility for the high-resolution powder diffractometer. The team concentrates on improvements to this diffractometer and on a variety of individual and collaborative efforts with partners both inside and outside NIST. Current efforts include predicting structural models from bond-valence principles; developing algorithms to make the general structure analysis system (GSAS; a commonly used Rietveld analysis program) more robust to missing phases; developing a user-friendly front end for GSAS; using neutron diffraction to determine crystal structures of new oxide and intermetallic superconductors and related materials; using neutron diffraction to study shape memory in intermetallic alloys and disordered intermetallic compounds; determining the phase changes of thermally sprayed yttria-stabilized zirconia; investigating proton siting in ZSM-5 (a zeolite-based heterogeneous catalyst) and investigating pore-size changes in titanosilicate zeolites; and investigating the dynamics of guest molecules in clathrates.

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. Members of the external crystallography community appear to find the work in this team relevant, but the ongoing efforts are not at the absolute forefront of national research in crystallography, in materials, or in data analyses. The team's work in support of the diffractometer is clearly effective and appropriate (see below), but the team needs to improve its vision of its role as scientists independent of providing hardware and software improvements for this instrument. The team should develop a new project or research topic that is uniquely suited to being tackled with neutron diffraction.

Staff are to be commended for their commitment to enhancing the effectiveness of the diffractometer and improving the effectiveness of users' interface with this instrument. Several improvements to the diffractometer have been made in the past year, including the replacement of the existing silicon monochromator crystal with a germanium crystal that has a new cut and orientation. The new germanium monochromator will theoretically yield a higher-intensity incident beam at the sample, although the impact of this change on data collected using the diffractometer will not be known for some time. The efforts to upgrade the capabilities of the diffractometer are important, as they make this instrument a more flexible alternative to instruments being developed for neutron powder diffraction at SNS. Other recent accomplishments in crystallography include the development of a new data collection front end for the diffractometer, new Web-based methods to monitor the instrument, Web-based access (via an intranet) to data archives, an expanded and improved GSAS user interface with standardized output, and new internal algorithms for GSAS. All of these efforts are appropriate projects and are consistent with the NCNR mission of developing and applying neutron measurement methods.

In diffraction applications, the team has a clear focus and definite goals, supported by a substantial outreach effort to several external communities. These interactions with outside scientists have helped the team staff put together a portfolio of projects that are particularly suited for neutron diffraction and have notable impact in external industrial and materials communities. The team's work includes determining strains and composition versus depth in plasma-sprayed and thermal barrier coatings, evaluating the parameters that control stress and elastic properties in sprayed coatings, determining stresses in new types of welds, relating weld stresses to crack propagation (in a collaboration with a well-known expert in plasticity modeling), determining local effects on elastic property uncertainties from analytical work and from modeling techniques using object-oriented finite element analysis, and working with the European Committee for Standardization to develop standards for neutron diffraction-based residual stress. These activities are consistent with NCNR's mission to develop neutron measurement techniques and to apply them to problems of national interest. Another example of a team project with national significance is the effort to verify experimentally (by measuring the stresses present in representative metal-formed parts) the stress distributions derived from finite element models being used by U.S. Council for Automotive Research and by the rail industry. In addition to using the residual stress diffractometer at NCNR and collaborating with researchers at organizations outside NIST, the team also takes advantage of other materials characterization techniques (e.g., orientation imaging electron microscopy, x-ray diffraction, SANS) and collaborates with other NIST units (such as the Metallurgy Division) to strengthen the quality and impact of its research efforts.

In addition to the research activities described above, the team is responsible for the neutron diffraction residual stress instrument. Experiments on this diffractometer fill an important role for the industrial and academic communities that need to perform residual stress measurements. This work is currently carried out by only three people and could benefit from at least part-time technical assistance with sample handling and instrument setup. Since the capability to do such residual stress measurements is not currently planned for the start-up phase of the SNS, it is likely that the residual stress instrument will continue to be a linchpin of certain user communities, and thus improvements to this diffractometer continue. This year, a doubly-bent monochromator was added, and a substantial increase in the intensity of the Fe(211) diffraction peak resulted.

Chemical Physics

The Chemical Physics Team carries out a number of projects for the study of the motion of atoms and molecules. Topics under investigation range from hydrogen bond dynamics in crystals to biopolymer dynamics in aqueous solutions. The scope of the problems attacked as well as the level of science is impressive, and interesting and important research is under way. One example is the use of Debye-Waller factors to study the thickness dependence of the time scales of local motion in polymer films. Such studies shed light on the nature of the glass transition, which remains a hotly debated area of condensed-matter chemical physics. Other work includes investigation of the nature of hydrogen bond hopping in large-unit cell crystals that have several modes for proton motion. These studies were very nicely complemented by simulations. Work of biological relevance includes measurement of the solution dynamics of proteins (cytochrome C) in native, unfolded, collapsed, and alpha-helical conformations. This is a proof-of-concept type of study to show that quasi-elastic scattering can provide information on protein structure in various buffer environments. Finally, the team has examined hydrogen diffusion in crystals where the lattice structure contains the motion to be highly anisotropic, 2d in this case. There exist only a finite number of hydrogen-containing interstitial sites with a substantial filling factor. These studies thus relate to the problem of 2d hopping in systems with strong excluded volume correlations; this fundamentally interesting problem could well engender strong interest in the theoretical community.

In addition to performing research, the Chemical Physics Team also is responsible for the scientific support for NCNR's five spectrometers, designed for inelastic/quasi-elastic scattering in different regimes. This collection of instruments enables experiments focused on times ranging from 100 ns down to 0.01 ps. This impressive dynamic range allows scientists to probe many types of nuclear motions in liquids and solids, and in the last operating cycle these spectrometers were used by more than 200 scientists from more than 50 institutions. As with other teams in NCNR, the Chemical Physics Team is making instrument development plans with the goal of becoming complementary to the SNS.

Condensed Matter Physics

The Condensed Matter Physics Team continues to carry out its strong research program. The focus is on problems at the forefront of the field of strongly correlated materials as well as important and interesting problems relevant to technological applications. Projects under way include work on elucidating the electronic underpinning of the unusual heavy electron Skudderudite $PrOs_4Sb_{12}$; the discovery of a new class of magnetic excitation in frustrated magnetic materials; an important study of spin-diluted La_2CuO_4 near the percolation threshold; investigation of edge states in Haldane gap systems; the finding of mesoscopic phase separation in a Fe/Re double perovskite; a study of digital ferromagnetic superlattices of Mn/GaAs, a system of great interest to the spintronics community; the determination that state-of-the-art high-density storage media have less than the expected optimal microscopic magnetic polarization characteristics; and an excellent study on the lattice dynamics of very-high-dielectric-constant relaxors. These projects address highly topical problems, and the results are published in leading journals, such as *Science* and *Physical Review Letters*. The powder diffractometer (BT-1), the spin-polarized triple-axis spectrometer (SPINS), and the polarized neutron reflectivity instruments have all been essential for carrying out this work. The team takes full advantage of its excellent external collaborations with researchers in industry, government laboratories, and universities, while maintaining strong rapport within the team, which has a strong staff of postdoctoral research fellows.

Life Sciences

In 2001, NCNR joined with five universities[5] to form the Cold Neutrons for Biology and Technology (CNBT) collaboration. This collaborative team recently received funding from the National Institutes of Health to support a variety of initiatives: a new diffractometer/reflectometer for biological structure studies, some time on the 30-m SANS instrument, staff members and postdoctoral research fellows (hired by the universities and placed at NIST), and new computer-modeling and laboratory capabilities. The subpanel commends NCNR's efforts to explore ways that neutron research can impact new scientific fields and believes that the work in this area has promise. The partnership with universities is appropriate, and obtaining funding from a new source (NIH) is a notable achievement. As NCNR moves forward in this area, challenges as well as opportunities will of course arise.

Planning for new projects of biological relevance or actual biology-related research is under way in several of NCNR's scientific groups. In the Macromolecular and Microstructure Science Team, staff will focus on using SANS to study the structure of transmembrane proteins. In the Chemical Physics Team, efforts have already begun in the uncharted and potentially crucial area of the dynamics of biomolecules, with the project on observing the solution dynamics of proteins (cytochrome C). This work may lead eventually to the quantitative investigations of biological functional dynamics at the molecular level; undertaking such studies would certainly be a worthy and timely venture.

The challenges facing NCNR as it moves into biological research relate mainly to the difficulties inherent in any change of focus at a research institution. 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. Building relationships with biological scientists is essential, as their expertise is needed to help staff determine which specific biological problems both would be susceptible to being tackled with neutron-based methods and would produce results of interest to key biological scientists. For example, what protein structures or dynamics should be studied? It is not currently clear to the subpanel who will perform outreach to biologists for NCNR. NCNR staff are not yet fully familiar with the relevant external communities, and the number of NCNR staff in this area is limited, so perhaps the university scientists in the CNBT will take on this critical task.

The lack of in-house staff with biological expertise raises other questions that NCNR must tackle as it moves forward in this new direction. Does NCNR want to expand the number of permanent personnel in this area, or will it rely on temporary staff and collaborators within and outside NIST? Currently, in addition to its university partners, NCNR is working closely with the NIST Biotechnology Division (of the Chemical Science and Technology Laboratory) on the biostructure work. In any case, NCNR will have to be prepared to adjust a variety of its standard experimental approaches to take into account the different kinds of samples on which biological research is focused. For example, in reflectivity studies in the surface and interfacial science area, the preparation of a biological sample will probably require a greater investment of time and effort than is typically needed for hard materials. The NCNR has indicated that it plans to add a wet laboratory on-site to support biology users, but the subpanel cautions that the equipment and safety issues for such a facility will be markedly different from those usually faced by NCNR staff, and NCNR should draw on those both within and outside NIST who have appropriate expertise to advise the center on the construction and use of such laboratories.

[5]The members of the NIH-funded CNBT are NIST, the University of California at Irvine, Rice University, the University of Pennsylvania, Duke University, and Carnegie Mellon University.

Reactor Operations and Research Facilities

The primary focus of reactor operations in the 2001-2002 period was a long-awaited, extended shutdown that began in August 2001. Major upgrades to the facility were carried out during this shutdown, including the installation of a new cold neutron source, replacement of the main electrical transformers and switchgear that supply electrical power to the reactor, and replacement of the cooling towers. In addition, temporary repairs were made to the leaking thermal-column cooling system. During the shutdown, the NCNR staff overcame a variety of obstacles and maintained an ambitious shutdown schedule; their performance was nothing short of astonishing. The reactor was restarted on March 8, 2002, only 1 week later than originally scheduled. It is a credit to the planning and resourcefulness of the operations management and staff that multiple large and complex projects were carried out simultaneously and were successfully accomplished.

From the perspective of the neutron research community, the most significant development was the installation of a new cold neutron source. The old source was highly successful and still functioned outstandingly, but NCNR management clearly recognizes the need for continuous improvement, and it actively supports and encourages innovation by members of the staff. The new cold neutron source is the culmination of several years of designing, machining, welding, and testing. Preliminary measurements of the cold neutron beam from this source indicate that a doubling of flux has been obtained at wavelengths from 0.02 to 1.0 nm, which means that design expectations have been met or exceeded. The subpanel is impressed by NCNR's willingness to undertake this long and complex task and applauds its success.

Replacing the main electrical power supply components and the cooling towers was essential for extending the life of the facility, and it had to be done to support the renewal of the reactor's operating license for another 20 years. Taking the electrical power supply out of operation was a particularly disruptive operation that had to be carefully planned and coordinated to minimize its impact on the other activities at NCNR during this shutdown. All went as planned with both replacement projects (electrical system and cooling towers). The one exception is that some rework is required on the cooling tower basin because of a contractor error in pouring the concrete. This oversight will be corrected by the contractor during a routine shutdown in warmer weather, and no impact on the operation of the towers is foreseen.

The final major activity of the shutdown was the work on the thermal column cooling system, which is located behind heavy radiation shielding. State-of-the-art fiber-optic inspection equipment was used to determine that the heavy water leaking within this system, originally suspected to originate only from piping, was also issuing from cracks in the welded seams of the aluminum thermal column tank. Temporary repairs to the tank were made, and a new tank is being designed and fabricated and should be completed by the end of 2002. It should be noted that a recurrence of leakage before the tank is replaced should not present a hazard, since any leaking water would be safely captured by a closed collection system.

Another leakage problem is occurring in the corroded copper tubes that carry cooling water for the bioshield. This is a recurring problem, currently at the level of no more than an annoyance, although it may worsen over time. Preemptive efforts are under way to develop a method for prevention or repair of such leaks without having to dismantle the bioshield. The feasibility of various techniques such as chemical coating, plating, and sleeving the internal surface of the copper tubing are being investigated as possible remedies for this problem. Ultimately, if these efforts are unsuccessful, eventual replacement of parts of the bioshield with its embedded cooling system may be required at some time in the future. This would be a significant undertaking, but far from impossible.

The shutdown occupied a great deal of the operations staff's time and attention, but appreciable progress continues to be made on preparing for the application to relicense the NCNR's reactor for another 20-year period. Several key facility upgrades were completed during the shutdown, and the focus is now on determining the expected lifetime of the aluminum reactor vessel. Bombardment by neutrons causes transmutation of the aluminum into silicon, which gradually causes the material to become less ductile. The rate at which ductility is lost depends on the particular alloy of aluminum used and the ratio of thermal-to-fast neutrons impinging on the vessel wall. The safety issue of concern is to determine when the vessel may become subject to stress-corrosion cracking or brittle failure. NIST has contracted with Brookhaven National Laboratory to develop a computational model of the reactor that will determine the neutron fluence and energy distribution throughout the vessel. If required, a materials surveillance program will be set up to periodically examine aluminum coupons taken from discharged vessel internals. The condition of the vessel itself could then be inferred from the calculated neutron fluence on the coupon and the condition of the material determined by metallurgical examination of the coupons. Computer modeling and any required tests could be completed in ample time to support the submission of the relicensing application at the end of 2003 or the beginning of 2004. NCNR is also making headway on the Safety Analysis Report, another key element of the relicensing effort. A draft of this report is due to be completed at the end of 2002 and reviewed during 2003.

The subpanel is impressed with the attention paid to safety at NCNR. The emphasis on safety is not limited to operations personnel or to the NCNR staff but is also evident in the training and work controls set up for more than 1,500 external users each year. Several new safety enhancements were added to NCNR during the extended shutdown. A walkway around the guide hall, where the instruments are located, has been painted bright blue to call attention to the fact that this area must be kept clear of equipment, cables, and other objects that might present tripping hazards or that might block egress in an emergency. Also, within the reactor building, the new electrical wiring that supplies power to the beamline instrumentation allows experimental equipment to be shut off from a location far enough away to protect personnel in the event of a fire or of high radiation in the immediate area of the equipment. These enhancements are evidence of management's strong commitment to a proactive approach to safety.

A key focus of safety efforts at all reactor facilities is minimizing the radiation doses received by staff. NCNR has an excellent record in this area. This year, larger-than-usual radiation doses (although still well within safe levels) were received by members of the operations staff and some contractor personnel during the shutdown, primarily as a result of the need to inspect and repair or replace highly radioactive components. As indicated by personal dosimetry monitoring, the total dose received by these personnel during the shutdown amounted to approximately 17 rem, most of which was associated with the cutting and removal of shields. Removal of the old cold neutron source and installation of the new one was also a "hot" job, giving personnel associated with the task a total dose of slightly more than 8 rem. Considering the complexity of this work and the high radiation levels that were present owing to activated components, the doses received were actually rather modest. (The highest individual doses were received by a contract welder [1.9 rem] and a reactor operator [0.9 rem]; these doses are well below established safe limits for occupational workers.) Nevertheless, the subpanel hopes that the experience gained during the recent shutdown will be used to plan even more effective methods for reducing the doses received by operations personnel in future high-radiation jobs of this nature.

Program Relevance and Effectiveness

The primary customer of 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 subpanel commends NCNR staff for their continued focus on effectively serving these users. During the past year, the facility served a total of 1,744 participants, including researchers from 49 different industrial organizations and 124 universities. Work done by these researchers and by NCNR staff provided the basis for more than 365 papers accepted or published in archival journals in FY 2001. Through these publications, the impact of the NCNR facility is felt even beyond its sizable user community. NCNR also continues to organize and host popular annual summer programs to train new members of the neutron science community. In the summer of 2001, 33 people, mainly graduate students and postdoctoral research associates, attended a week-long course on methods and applications of neutron spectroscopy; preparation is already under way for the 2002 program on neutron small-angle scattering and reflectometry from submicron structures.

Many different models are used to support the users of 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. An NCNR Users Group exists (run by and for the users to address air concerns and needs), but the subpanel was informed that this group has little to do because users are, on the whole, remarkably pleased with the quality of the instruments available and the support received at NCNR.

A major facilitator of the external use of NCNR instruments is the National Science Foundation (NSF), which supplements NIST support for the Center for High Resolution Neutron Scattering (CHRNS) at NCNR. CHRNS consists of six instruments, the 30-m SANS at NG-3, the USANS, the SPINS, a time-of-flight disk-chopper spectrometer (DCS), a high-flux backscattering spectrometer (HFBS), and a neutron spin echo (NSE) spectrometer. The last three instruments were added to the CHRNS umbrella this past year, and NSF's support of these inelastic scattering instruments has allowed NCNR to expand the amount of user time available on them. However, the applications for this newly available beam time still exceeded the amount of time being offered; the user base and desire for access to these instruments clearly exist.

NCNR staff have recently made a number of commendable efforts to improve user experiences at their facility. The development of new instruments and the upgrades of older instruments continue, and current plans call for the eventual refurbishment of all the thermal instruments, which will result in a significant improvement in the overall capabilities accessible at NCNR. A past concern has been the quality of the data-gathering and analysis tools available to users, and the neutron science and research facility operations personnel have devoted a significant amount of effort to improving the situation. New tools developed during the extended 2001-2002 shutdown include the data analysis and visualization environment (DAVE) software for treating and analyzing time-of-flight, backscattering, and triple-axis data sets and the data reduction and analysis software (IGOR) for SANS and USANS data. The effectiveness of these programs will be tested by users in the next round of experiments.

Other new approaches designed to improve user experiences include the recent hiring of two SANS "operators," who will be present at the start of each new experiment undertaken by a team of external users. Before each new team arrives, the operator will ensure that all equipment needed for mounting, maintaining, and demounting samples is ready for use and that the data acquisition and computing resources at the SANS instrument are in good working order. The operators can assist with setting up spectrometer configurations that have been predetermined by the users and the instrument scientist contact at NCNR; with mounting sample holders and other ancillary equipment such as constant-temperature environments, magnets, rheometers, and so forth; and with identifying and solving problems that otherwise might create hardships for the users of the SANS instruments. The subpanel expects that these personnel will provide an excellent enhancement of NCNR's already-strong resources for user assistance.

While the primary focus of these new approaches to user support is enhancing the users' experiences at NCNR, another important benefit is that of using NCNR personnel's time more efficiently. This not only enables NCNR to support an ever-increasing number of users at the facility but also allows the in-house staff to spend time on their own research activities and not be overwhelmed by instrument support obligations. The increased flux provided by the new cold neutron source will reduce the amount of beam time needed for some types of experiments and will make new types of research possible, and so both more and new users will probably be drawn to NCNR. It is not clear to the subpanel that if the number of users increases significantly, the current staff level will be adequate to provide the high level of scientific and technical support that NCNR users are accustomed to receiving.

Different neutron science teams at NCNR have different approaches to their respective external user communities. The Macromolecular and Microstructure Science Team is very active in promoting use of its instruments by researchers from academia, industry, and government laboratories, through instrument Web sites, individual contacts, and extensive participation in conferences. The Surface and Interfacial Science Team works with an extraordinarily active user community for the reflectivity instruments, whose beam time is always oversubscribed; here the typical mode of operation with outside users is through collaborations. In the Crystallography and Diffraction Applications Team, the availability of on-site staff for assistance with the BT-1 and BT-8 diffractometers is particularly attractive to industrial collaborators, who are often pressed for time and generally have inadequate personnel resources of their own to devote to complex instrument setup.

In general, methods of interacting with industrial users vary across NCNR. On some instruments, companies provide support through participating research teams (PRTs); on other instruments, staff have very active nonproprietary industrial collaborations; and on some topics, practically no interactions with industry occur. Although not all teams are equally engaged with liaisons with industry or receptive to the possible performance of proprietary work, the spectrum of interactions appears to represent a good overall balance for NCNR-industrial interactions. However, the software tools and support for some instruments are so clearly designed for open, nonproprietary work that an industrial user would be severely handicapped if an attempt was made to do proprietary work at NCNR on those instruments.

For instruments on which beam time is available to the general scientific community, that beam time is allocated by the Program Advisory Committee (PAC). This advisory committee is composed of nine neutron scientists (not from 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 have exceeded the number of days available—in several cases by a factor of 2.5 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, and when the subpanel 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.

A past concern of the subpanel, NCNR management, and the PAC itself has been the rising number of proposals that the PAC must review. (This growth is due in part to the increasing number of instruments, and time on those instruments, open to users.) 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 is looking back at the first round of program grant awardees to check the level of output (i.e., publications) to ensure that good use is being made of the beam time, and the PAC is looking forward to preparing for the second round of program proposals by defining more clearly who may apply for these grants and by adjusting the criteria for the awards and making the criteria uniform across the instruments.

The PAC has managed to adjust well to changing circumstances, and the subpanel notes that in addition to the increasing number of proposals the PAC will also soon be facing changes in the types of proposals received, as NCNR's emphasis on biological applications of neutron science expands. New instruments and new uses for existing instruments will arise. The expertise on the PAC will have to evolve to allow the PAC to deal effectively with all these changes. The subpanel suggests that the PAC and 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 would allow members to understand the length of the commitment they are making to the NCNR and would enable the expertise of the membership to be adjusted to reflect new priorities and directions at the center.

Resources

Funding sources for the NIST Center for Neutron Research are shown in Table 6.6. As of January 2002, staffing for NCNR included 90 full-time permanent positions, of which 83 were for technical professionals. There were also 18 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

NCNR continues to accomplish an amazing amount with very little money compared with the budgets of, for example, DOE user facilities. 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; CHRNS has been expanded, and work on a new instrument, a multi-analyzer crystal spectrometer (MACS), is under way with NSF and Johns Hopkins University. The CNBT, discussed above, involves five universities and

TABLE 6.6 Sources of Funding for the NIST Center for Neutron Research (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	14.5	15.9	15.5	15.6
Competence	0.2	0.2	0.1	0.1
ATP	0.3	0.3	0.3	0.0
OA/NFG/CRADA	1.6	1.9	2.7	1.6
Other Reimbursable	0.2	0.2	0.1	0.2
Total[a]	16.8	18.5	18.8	17.6
Full-time permanent staff (total)[b]	85	85	92	90

NOTE: Sources of funding are as described in the note accompanying Table 6.1.

[a]Totals for NCNR include only normal operation costs. Fuel cycle and upgrade costs associated with the reactor, totaling approximately $6.8 million in FY 2002, are excluded.

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

NIH. An agreement is in place with Brookhaven National Laboratory for a long-term alliance to support work on new magnetic and ferromagnetic materials. All of these partnerships bring funding and expertise to NCNR.

The subpanel is pleased to see that support for reactor operations and engineering continues at all levels of management above NCNR (in the Materials Science and Engineering Laboratory, in the NIST director's office, and at the Department of Commerce). This support has been critical for the safe and productive operation of the research reactor, and it is to be commended.

A strong and healthy internal science program is a vital element of the vibrant research atmosphere that exists at NCNR. Unfortunately, funding for the science activities has been squeezed over the past several years, as the priority is always (and appropriately) maintaining the reactor, and then the instruments, in good operating condition. Thus, the $6 million neutron science initiative in NIST's FY 2003 Presidential Budget is critical. This new funding would go toward instrument operation, user support, and, most importantly, science. While not entirely dedicated to science at NCNR (it would also support relevant materials science, physics, and chemistry research in other NIST laboratories), this funding would be a great opportunity to strengthen the science activities of NCNR's condensed-matter science teams. It would also provide the freedom to move in new strategic directions, that is, to add new in-house expertise in biology. A strong and diverse intramural science program is critical to driving creative instrument development and to effectively serving a vigorous user community drawn from a wide range of scientific fields.

One of the primary drivers for expanding the support of the science programs at NCNR is ensuring that the NCNR scientists are not overwhelmed by routine user-support tasks. It is vital for staff to have time to perform their own research and to reach out to research communities. Such outreach builds awareness of the applicability of neutron science techniques to a variety of scientific problems, keeps staff informed of new developments in their own fields, and allows NCNR to build a reputation that will assist it in recruiting postdoctoral research associates and permanent staff. Communication with people outside NIST who do neutron research must be supplemented by contact with people from the broader communities that benefit from the results of NCNR users' research. These interactions will help NCNR staff to understand and describe the motivation and context for their work, the applications enabled, and the important and interesting scientific questions tackled. A formal and active visitors program might be one approach to bringing in new expertise or perspectives (such as in theory or biology) that are not available on a permanent basis at NCNR.

Another key element of external interactions is access to expertise or equipment not available on-site. Research is almost always strengthened by looking at a problem from a different perspective or with a different tool. For example, in the surface and interfacial science area, neutron reflectivity is a powerful approach, but complementary x-ray reflectivity measurements of a given sample often provide useful added information. While such x-ray experiments typically have required access to a synchrotron facility, in fact adequate measurements can be made with properly instrumented laboratory x-ray sources. The recent acquisition of an x-ray reflectivity instrument located on the NIST campus in the Materials Building (235) will thus be helpful to the NCNR staff and to users performing reflectivity measurements. This is just one example of the potential synergies between NCNR and the expertise, projects, and facilities available throughout the rest of NIST. Other facilities that might productively be shared include nuclear magnetic resonance spectrometers; other expertise that might be tapped includes theoretical and modeling capabilities. While NCNR is physically somewhat isolated from the rest of the NIST campus, shared equipment or cohosted talks might provide the basis of some productive, long-term relationships.

Access to theoretical expertise for NCNR internal science projects has been an ongoing point of concern for this subpanel. Currently, NCNR is obtaining some input in this area and does have ongoing modeling and simulation work, but the subpanel continues to believe that NCNR's programs would benefit from increased theoretical input. Theory can provide new or different perspectives on existing problems and can be a source of new problems or topics to explore. Theoretical expertise can be brought to NCNR in a number of ways. As mentioned above, one is collaborations or interactions with theorists from other NIST units. A second possibility is a visitors program, although this approach works best when there is a theorist on the permanent staff who can help the visitor connect with the appropriate NCNR staff or if there is a preexisting collaboration between the visitor and NCNR experimentalists. A third possible approach is hiring a person who does both theoretical and experimental work, and a fourth option is hiring an experimentalist who has a history of attracting theorists (as visiting scientists or collaborators) for his or her work.

Staff morale is high at 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. 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 NCNR's responsibility to the neutron community.

Each year, the subpanel comments that three of the four most senior managers at NCNR will shortly be or already are eligible for retirement. 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 NCNR. The transition plan and process will deserve close attention by MSEL and NIST management, and the subpanel believes that all parties recognize this need. The subpanel also notes that transitions and change, while potentially sources of tension and stress, can also be times of great opportunity, and the next few years will also give NCNR a chance to consider new focus areas and to move in new directions.

The issues related to succession planning and training are particularly critical in the reactor operations area. 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. The U.S. Navy continues to be a source of highly qualified operations and maintenance personnel, but recruiting and retaining management and engineering personnel of the same high caliber as those who may be retiring could become a problem in the near future; with the dwindling number of U.S. research reactors has come a sharp reduction in the pool of experienced managers and engineers who will be available. Although NIST still has a recruiting advantage (owing to a desirable, semiurban location and the opportunity to work with the cutting-edge technology used at this facility), succession planning and searches for qualified candidates should continue to be conducted well in advance of anticipated vacancies.

Space continues to be tight at NCNR, although progress on this issue is being made. The addition to the building has been completed. Office and laboratory space is being reorganized to take advantage of this new space and to make on-site laboratory support available for users. As noted earlier, plans are being made to add wet-laboratory capabilities to support biological experiments.

Site security became a high-visibility concern after September 11, added precautions were taken in the fall of 2001. If more security measures are required, NCNR might consider looking at approaches used at other government and industrial laboratories to control site access (e.g., computer tracking of visitors at Brookhaven National Laboratory or photo identification cards for visitors as used in industry and at NIH). The subpanel strongly believes that security is the responsibility of the federal government as a whole, and additional money should be allocated to NCNR to fund new security measures.

Responsiveness

The subpanel believes that NCNR has been responsive to comments and suggestions provided in past assessment reports. Most of the issues raised in these reports are long-term, and the subpanel looks for annual progress rather than complete resolution. For example, succession planning and the training of future leaders are serious tasks at NCNR, given the demographics of the current management personnel and of the staff in reactor operations. Each year, the subpanel 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. Another concern of the subpanel is that scientific staff be able to balance time spent on routine support of users with research and instrument development projects. In response, NCNR is investigating ways to automate tasks and hire technicians dedicated to user support. The neutron science initiative proposed in the FY 2003 budget, if funded, will provide an important opportunity to strengthen the science programs at NCNR and expand in new directions.

Other examples of positive changes at NCNR reflect NCNR's responsiveness not only to the subpanel 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 subpanel and the users and should, therefore, be commended.

Major Observations

The subpanel presents the following major observations:

- 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 receive support.
- NCNR management and staff do not rest on past accomplishments but are dedicated to continual improvement of the facility. New instruments are developed and old ones enhanced. The relatively young cold neutron source was replaced with a new and better version, and a new scientific focus on biology was launched. The dedication of the staff to effectively serving NCNR's users is impressive.
- Decisions about instrument development take into account the eventual construction of the SNS, and plans are made with the short-term goal of training and maintaining a robust U.S. neutron science user community for the SNS and the long-term goal of providing critical complementary capabilities once the SNS is operating.
- Reactor operations continue to be first-class. During the recent extended shutdown, the time was used effectively to accomplish several major, complex repairs and improvements. The subpanel is also pleased to note that relicensing plans are on track.

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Building and Fire Research Laboratory

PANEL MEMBERS

Janet S. Baum, Health, Education & Research Associates, Inc., *Chair*
Robert A. Altenkirch, New Jersey Institute of Technology, *Vice Chair*
Craig L. Beyler, Hughes Associates, Inc.
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
Eric R. Hansen, Eric Hansen Group
Kristin H. Heinemeier, Brooks Energy and Sustainability Laboratory
Robert J. Hitchcock, Lawrence Berkeley National Laboratory
Susan D. Landry, Albemarle Corporation
Elaine S. Oran, Naval Research Laboratory
Richard E. Schuler, Cornell University
Jim W. Sealy, Architect/Building Code Consultant, Dallas, Texas
Frieder Seible, University of California, San Diego
Michael Winter, United Technologies Research Center
Elaine M. Yorkgitis, Automotive Division/3M

Submitted for the panel by its Chair, Janet S. Baum, and its Vice Chair, Robert A. Altenkirch, this assessment of the fiscal year 2002 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 28-March 1, 2002, in Gaithersburg, Md., and materials provided by the laboratory.

LABORATORY-LEVEL REVIEW

Technical Merit

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.

Strategic Planning

As recommended by the panel in the 2001 assessment report, BFRL has started work on a strategic plan, which was in an early stage when the panel visited the laboratory in February 2002. The panel is supportive of this effort, which should lead to a coherent, long-term strategy for the laboratory.[1] Such a strategy will assist the laboratory in seizing the opportunities and meeting the challenges related to BFRL's role in the area of homeland security, as discussed below.

The next steps for the laboratory in developing a strategic plan are as outlined in the panel's previous report. BFRL management should seek assistance and input from a variety of sources, including professional outside facilitators with experience in the process. It should solicit technical input from current and potential customers to help determine their priorities and what types of results are most likely to be implemented by industry. Finally, BFRL should tap the expertise of its junior and senior technical staff; they are familiar with cutting-edge technologies and are attuned to the activities of the external communities and the reactions of these communities to NIST efforts. As of February 2002, the NIST-level strategic plan is scheduled to be completed in June 2002; the panel notes that BFRL's plan to coordinate the NIST-level vision and goals with the laboratory-level plan is appropriate.

As BFRL moves forward, the panel offers several comments on strategic planning. First is the value of a sharp, clearly defined vision for the *future* of BFRL; this vision would not be a description of the current activities of the laboratory or a statement reflecting the laboratory's reaction to past events. Second is the need for the plan to be developed from two perspectives: the top-down vision and goals that are the ultimate responsibility of management and the bottom-up goals, objectives, strategies, and tactics that make up the implementation element of the plan and must reflect the input and support of divisional management and staff. Third is the importance of quantitative metrics, both short- and long-term. Such metrics have two primary benefits: they support an environment of accountability and they, if relevant to the laboratory's customers, can be used to demonstrate the value, impact, and progress of BFRL's activities. Fourth is the need to define a unique niche for BFRL. The panel observes that many, although not all, of the laboratory's programs already clearly recognize and take advantage of BFRL's singular attributes, such as its role as an unbiased evaluator of technologies and developer of tests. Fifth, and perhaps most important, is the need to engage the laboratory staff in the strategic planning process and to obtain their agreement on and buy-in to the vision, goals, objectives, strategies, and tactics that BFRL intends to embrace going forward.

[1]"The key benefits would be having a coherent and stable definition of goals and programs through which the laboratory could effectively establish an organizational culture internally and present a consistent face externally. The plan, and the process of determining the plan, could also help resolve internal uncertainties about the laboratory's future and the direction of individual projects and programs." 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., September 2001, p. 195.

Homeland Security

As the federal government responds to the national tragedy of September 11 and moves forward with nationwide efforts to protect the United States, BFRL has an important and unique role. The panel heard about a wide array of planned laboratory activities in support of homeland security. Some work is already under way, or even completed, such as a code comparison study for the Federal Emergency Management Agency (FEMA), a study of Pentagon repair and rebuilding plans, modeling and simulation of the ventilation system of the Hart Senate Office Building, and simulations of the fires in the World Trade Center. Most of the work, however, is still to be done. The laboratory's plans through FY 2005 and beyond fall into three categories. The first is the national building and fire safety investigation of the events at the World Trade Center. The second category encompasses three programs: structural fire protection; human behavior, emergency response, and mobility; and building vulnerability reduction. All three programs are expected to include research, testing and verification, demonstrations, development of improved tools, guidelines for industry, and finally revisions to standards and codes. (In the upcoming "Program Relevance and Effectiveness" section, the panel discusses the importance of this last step.) The third category is an effort to develop a national forum through which industry can lead the dissemination of information about research and encourage the adoption of new practices in construction. In all of these categories, the laboratory plans to partner with a wide variety of external organizations, including federal, state, and local governments, professional societies, industry consortiums, and universities.

The panel is very supportive of BFRL's efforts in homeland security, and encourages the laboratory to take full advantage of this opportunity to make an impact in a critical area and to demonstrate the relevance and importance of the areas and expertise already existing in the laboratory. The BFRL program described briefly in the preceding paragraph is appropriate and ambitious, and BFRL must be vigilant in balancing the short-term focus of the investigation work with the long-term development of research and applications that are broadly relevant. As the laboratory moves forward in the area of homeland security, it must not lose sight of BFRL's core mission and customers. The activities outlined above can be consistent with long-term goals and directions of the laboratory, especially if the projects are structured to build on existing expertise and work and if the benefits and dissemination of the new efforts to existing customers are carefully considered as the homeland security efforts are being defined. For example, work on the structural behavior of buildings in fires, on the dispersion of biological agents through building ventilation systems, and on the integration of building information technology systems all can build on existing laboratory expertise, are relevant to a wide range of BFRL customers, and could use the expansion from homeland security work to seed continuing programs consistent with long-term laboratory goals. BFRL has worked hard to build relationships with a broad variety of industries, federal agencies, associations, and other communities. It should not be forced by a homeland security agenda to abandon these interactions, because this existing web of connections is at the heart of the laboratory's ability to meet the measurement and standards needs of the building and fire safety communities, as stated in its mission.

An important element in the laboratory's maintaining focus on its broad mission is its access to the expertise needed to tackle the challenges associated with the ambitious homeland security agenda. While key core technical expertise certainly exists in the laboratory, a wide range of other skills will be needed, particularly to complete the World Trade Center investigation phase of the project. The laboratory clearly stated to the panel that the plans require BFRL to tap into engineering and social science expertise outside NIST and that it expects to work with an array of government agencies, professional societies, and other organizations. The panel applauds the laboratory's recognition of the need to utilize external groups. However, it is important to recognize that an undertaking of this magnitude and diversity also requires specialized contract, personnel, and project management skills, as well as significant public relations work. NIST should not dilute the scientific efforts that BFRL is uniquely qualified to carry out by burdening technical staff with large-scale project or contract management tasks. Laboratory and division management also should be allowed to maintain their focus on BFRL's core activities and on how the homeland security efforts link with long-term laboratory goals. Therefore, the laboratory needs to develop a workforce management plan outlining all of the people and skills that will be needed, indicating how NIST will access those people and skills, and identifying how the people and the projects will be managed.

Technical Highlights

The Building and Fire Research Laboratory is organized in four divisions: Structures, Building Materials, Building Environment, and Fire Research (see Figure 7.1). Each of these divisions is responsible for one of BFRL's four 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 laboratory office on a variety of activities, mainly in the Office of Applied Economics (OAE). These units and activities are discussed in detail in the divisional reports in the remainder of this chapter.

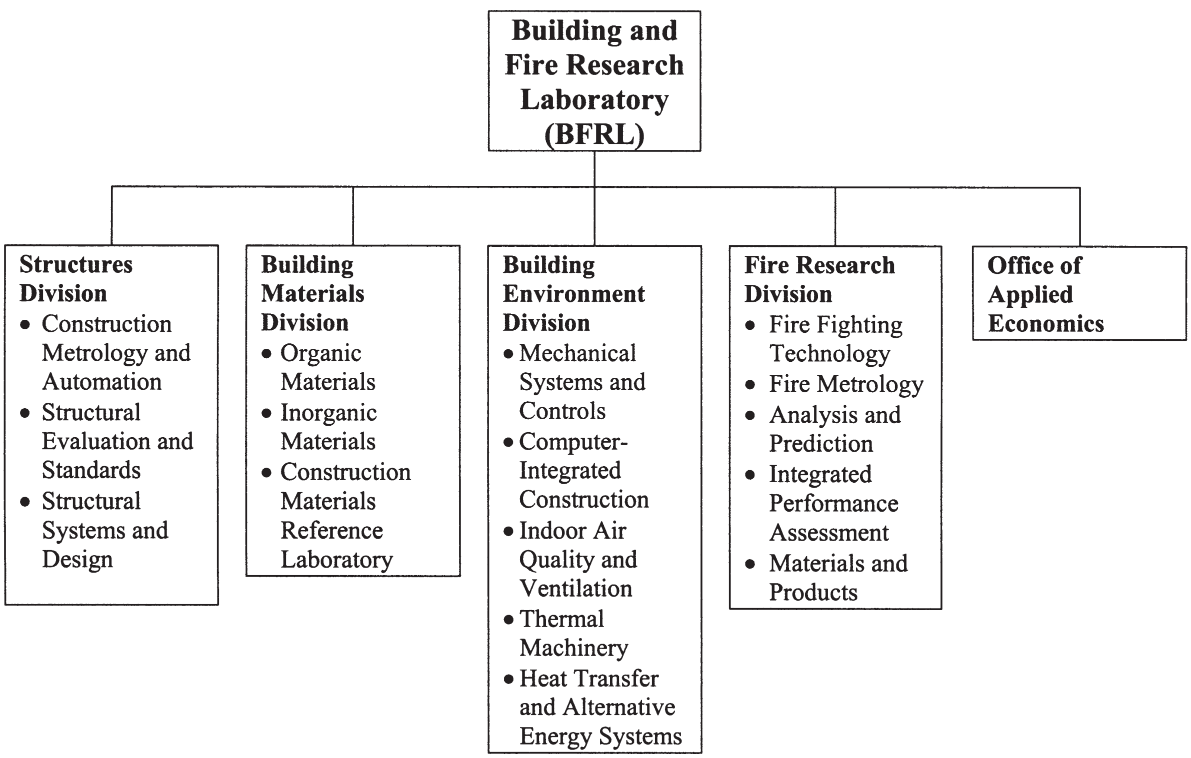

FIGURE 7.1 Organizational structure of the Building and Fire Research Laboratory. Listed under each division are the division's groups.

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 utilize 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.

In the technology areas, often NIST's role is that of developing metrics for performance or standards that will allow interoperability. In the Structures Division, the panel was impressed by the work on metrics for nondestructive evaluation using infrared thermography and on metrics for construction range imaging and registration using laser detection and ranging (LADAR) systems. These activities lay the groundwork needed to help industry develop efficient, standardized technologies for tracking and monitoring components during the construction process. In the Building Environment Division, a robust program in cybernetic building systems exists. Highlights of these efforts include long-term work on the Building Automation and Control network (BACnet) and on fault detection and diagnostics, as well as new efforts in building commissioning. In these areas, staff aim, through technical work and participation on standards committees, to support the development of building systems that will interoperate seamlessly and enable more efficient operation of buildings throughout their life cycles.

BFRL enables industry's efficient investigation of new and better materials in several ways. In the Fire Research Division, staff have developed a system to allow polymers to be extruded so as to produce a sample with a continuous gradient in composition. This sample allows researchers to determine flame spread continuously as a function of composition and flux level. In the Building Materials Division, the staff's world-class expertise in the computational materials science of concrete has resulted in the development of the Virtual Cement and Concrete Testing Laboratory (VCCTL), which is available on the Internet. This program helps concrete manufacturers eliminate the formulations less likely to have the desired material characteristics and thus saves time and money for the producers by allowing them to focus physical testing activities on only the most promising formulations.

Organizational Changes

Organizationally, BFRL is going through a series of changes. In late 2000, the Fire Research Division was formed from the combination of two divisions. In last year's assessment, the panel noted that the potential positive impact of this merger was high. At that time, the delicate process of blending the two groups was just beginning. The panel is pleased to report this year that the transition is 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. While the process of merging is not complete and the goals of the new division continue to evolve, the panel applauds the work done so far, including the positive impact of divisional and laboratory management's emphasis on communications during the merging process.

This year, the panel was informed of a plan to merge two more divisions: Structures and Building Materials. 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 structural performance requirements. This is an ambitious and long-range goal, and making clear exactly what the connections and synergies between the diverse groups in these two divisions are and then utilizing them to greatest advantage will be challenging, but the potential payoff is significant. Plans for how the merger will go forward are being drafted. The laboratory wisely intends to move slowly on this complicated task, which is scheduled to be completed sometime in the next year or so. The key challenge will be bringing together the different cultures in the divisions, each of which has a distinct set of customers, dissemination models, and technical approaches. Leadership and communications are vital. Both divisions are small and the chief of the Building Materials Division recently retired, so laboratory management must be clear on the strategic benefits of the merger lest it be viewed merely as a reactive personnel move.

Program Relevance and Effectiveness

As mentioned above, laboratory staff have made a significant effort to build relationships with their customers in a wide variety of industries and communities. The approaches to outreach include publication in technical peer-reviewed journals as well as the more popular press, industry consortia focused on common research agendas and measurement technology development, workshops attended and hosted by NIST staff, road-mapping activities by professional organizations and consortia, collaborations with and visits to and by individual companies, research projects with and for other government agencies, and active participation on standards committees. These activities serve a dual purpose—they provide BFRL staff with a chance to gather input from their stakeholders, and they afford an opportunity to disseminate information about laboratory results and ongoing projects. The panel commends the focus placed by the laboratory on outreach activities; the examples below illustrate the diversity of approaches.

In the Fire Research Division, the work on residential smoke alarms not only has provided key data and test methods to the manufacturers of the alarms, but the press release and media coverage of the work have also allowed the laboratory to reach ultimate users of the alarms: the public. In the Building Materials Division, the first year of the VCCTL Consortium went particularly well; several of the world's largest cement and admixture manufacturers, a number of major trade organizations, and the International Center for Aggregate Research are involved. In the Structures Division, the staff's many committee activities help maintain their relationship with other researchers. The September 2002 International Symposium on Automation and Robotics in Construction organized by the division is an important event for the professional and academic communities, and the involvement of NIST in FIATECH's Capital Projects Technology Roadmap[2] is an excellent part of this much-needed effort to synchronize the work of industrial, academic, and government laboratories. The staff of the Building Environment Division are using their existing tools and expertise in the area of modeling the distribution over time of contaminants (such as pollution or smoke) through building ventilation systems to contribute to homeland security efforts. Not only did they help with the analysis of the Hart Senate Office Building after its anthrax contamination in the fall of 2001, they are also working with the Architect of the Capitol and with the State Department to preemptively develop models of ventilation systems of critical buildings before any attack or contamination occurs.

The many efforts at outreach described above demonstrate that the laboratory works very hard to ensure that relevant communities are aware of BFRL results. This is certainly true in the codes and standards arena. Throughout the laboratory, staff appear to take NIST's core measurements and standards mission to heart. Research on tests methods, on materials and technology characterization, and on standards is occurring in all divisions. Staff have good individual relationships with standards commit-

[2]FIATECH was organized by NIST and the Construction Industry Institute in 1999. It is an industry-led, collaborative, not-for-profit research consortium serving the construction industry. FIATECH stands for Fully Integrated and Automated Technology.

tees, such as those organized by the American National Standards Institute (ANSI), the American Society for Testing and Materials (ASTM), and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

A vital step in ensuring that BFRL results have an impact on advancing technology and on improving the quality of life is ensuring that laboratory results are broadly used and adopted into standard practice. In the construction industry, this is accomplished by having BFRL's technical knowledge and results reflected in codes. Influencing codes is a complicated process that requires political skills and careful timing. For the laboratory to be successful in this arena requires top-level support for and central coordination of codes and standards activities across BFRL. This coordination is necessary both for communicating to staff within the laboratory about opportunities to influence codes and for monitoring the activities of codes and standards agencies and providing outreach to these groups. Potential areas of intralaboratory synergy should be recognized and collaborations facilitated. The expertise in the Office of Applied Economics can also be tapped to help the laboratory demonstrate the economic value and impact of new standards or technologies.

Two years ago, the informal leader of the laboratory's codes and standards work retired, and this past year, the BFRL liaison to the National Science and Technology Council's Subcommittee on Construction and Building also retired. Recently, the laboratory management embraced a plan to support half of one staff member's time to be dedicated specifically to codes and standards activities. This is an important first step, and the panel applauds the recognition of the importance of work in this area. However, one-half of one person's time is not sufficient to accomplish the coordination and outreach necessary for BFRL to impact the wide array of codes and standards that the laboratory has the expertise to affect and improve. In addition, the plan for that staff member's goals and activities was written in the summer of 2001 and needs to be revised and expanded.

The events of September 11, 2001, have forced the codes and standards community to reconsider many existing regulations and to be open to new ideas. This is an opportunity for BFRL to demonstrate technical leadership and to have significant impact. However, regulatory changes will occur on a very tight, already-determined schedule, which means that the laboratory has a limited window of opportunity—that is, BFRL's work must be completed before the end of 2005 to be included in the codes revision processes. While time is short and meeting this schedule is an ambitious goal, the panel believes that the laboratory can accomplish it, in large part because of previous work and existing expertise in the relevant areas. Examples of these areas include structural fire safety, communications and data for first responders, and evaluation of exiting technologies. In addition to enabling the regulatory community to utilize NIST's technical expertise and results effectively, the laboratory also can help the community focus on the areas with the broadest potential impact. While the tragedies of September 11 resulted from specific (and hopefully very rare) terrorist attacks, the lessons learned about structures under stress can be applied to make all buildings safer.

Laboratory Resources

Funding sources for the Building and Fire Research Laboratory are shown in Table 7.1. It has not yet been determined how much new, congressionally allocated funding BFRL will receive to be specifically targeted toward homeland security activities, but a significant amount of money (perhaps $15 million in FY 2002 and $6 million per year after that) will flow to laboratory programs. The panel was 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 this program. Laboratory management indicated the level of its commitment to work in this area by quickly reprogramming roughly $2 million of its own funds

TABLE 7.1 Sources of Funding for the Building and Fire Research Laboratory (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	16.4	16.6	18.8	20.5
Competence	0.4	0.2	0.2	0.0
STRS, nonbase	1.8	1.5	1.9	1.7
ATP	0.6	0.7	1.1	0.3
MEP	0.2	0.1	0.0	0.0
OA/NFG/CRADA	9.2	11.2	9.1	11.3
Other Reimbursable	0.1	0.2	0.1	0.2
Total	28.7	30.5	31.2	34.0
Full-time permanent staff (total)[a]	157	157	150	152

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). 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.

to tackle key questions, such as the work done on modeling the ventilation systems of the Hart Senate Office Building, as they arose last fall. While this was a good and appropriate step, the laboratory must be cautious going forward to make careful decisions about such reprogramming—that is, 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 security work and existing projects.

Another question about how this perhaps temporary, specifically targeted funding will affect BFRL relates to the laboratory's attitude toward and treatment of external funding sources (i.e., contracts with other government agencies). The assessment reports of the past several years have discussed the importance of having clear criteria for seeking and accepting external money. While the panel does not see evidence that such criteria are in place or are shaping staff's decisions about outside funding yet, it does note that development of a strategic plan may help define and implement these criteria. Indeed, a strategic plan will need a core commitment of internal money or stable external funds to support a long-term vision, and such a commitment may be needed if management is to convince the staff to embrace laboratorywide goals.

One source of stable outside money could be a long-term formal relationship with FEMA in which NIST would officially be responsible (and funded) for providing research elements to support FEMA's activities. On April 1, 2002, NIST and FEMA announced the signing of a memorandum of understanding (MOU) that designates NIST as a research and technical resource for FEMA. Under this agreement, BFRL and FEMA's Federal Insurance and Mitigation Administration (FIMA) will work jointly to carry out these goals:[3]

- Further the reduction of loss of life and property and protect the nation's buildings and infrastructure from all types of hazards;
- Aid the development of technology and methods to evaluate equipment for use by the nation's fire, rescue, civil defense services, and other first responders; and
- Assist FEMA with scientific and technological services in disaster investigations, recovery planning, and support technologies.

The MOU also states that NIST and FEMA have agreed to develop and implement a coordinated annual process to plan, prioritize, select, and fund projects of mutual interest in fire, disaster prevention, and homeland security—as well as projects to evaluate equipment for fire, rescue, and civil defense services, and other first responders. BFRL has worked hard for the past several years on establishing the commitments needed to put a formal relationship in place, but the process had been delayed by changes in the administration and the events of last fall. The panel believes that having this formal agreement is appropriate and important and applauds the laboratory's efforts and success. Next year, the panel hopes to hear about what benefits this MOU has brought to both parties.

As of January 2002, staffing for the Building and Fire Research Laboratory included 152 full-time permanent positions, of which 129 were for technical professionals. There were also 35 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The number of permanent staff in BFRL declined in the late 1990s but now appears to have stabilized. This stability has had a positive effect on morale and should facilitate long-term planning on program direction and acceptance of external funds. In particular, an understanding of the expectations for long-term staffing levels should allow the laboratory to focus on talent replacement and 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 develop a vision of what a state-of-the-art facility for large-scale structural fire testing should be and of what the test objectives should be, and that it map

[3]From the MOU between FEMA and NIST, available online at <http://www.nist.gov/public_affairs/releases/nistfemamou.htm>.

out a development and implementation strategy to secure funding and build the program. Proposals for such a facility do exist at BFRL, but they were developed some time ago (certainly before September 2001), and they should be revisited to ensure that the proposal made is sufficient to build and support a facility that will be at the center of a long-range program. This effort would also be a good opportunity for the Structures and Fire Research Divisions to build closer working relationships in this area.

The value of cross-divisional collaborations is clearly recognized in BFRL, and the panel saw progress in the quality of staff interactions across organizational lines over the past year. In certain areas, informal relationships are very effective in ensuring that laboratory projects take advantage of the cross-disciplinary synergies available in BFRL. In other, larger-scale programs, formal coordination at the laboratory level may be necessary. Work on information technology systems is occurring throughout the laboratory—the Structures Division has projects on construction automation, the Building Environment Division has projects on the integration and management of building systems, and the Fire Research Division has models, simulations, and detector projects—and coordination of these activities could help ensure that appropriate collaborations continue to occur and that full advantage is taken of the opportunities to leverage complementary skills.

The panel commends the laboratory on its continued progress in internal communications. The formation of a junior advisory board, the evolution of the merged Fire Research Division, and the general healing observed after the stressful events of FY 2000 (including some potential and actual reductions in force) all indicate that BFRL has recognized the importance of improving communications within the laboratory and has made a significant and successful effort in this area. Plans for formal mentoring were mentioned to panel members, who suggest that such relationships should not be formed solely among technical staff but should also include managerial mentoring.

Laboratory Responsiveness

The panel found the laboratory on the whole to be responsive to recommendations made in past assessment reports. In several areas, the panel was particularly impressed. The Thermal Machinery Group is to be commended for acting on the panel's recommendation for removal of methylene chloride from the truck environmental chamber cooling system and for cooperating with the NIST Physical Plant unit to obtain adequate funds to completely revamp the cooling system valves and controls. Both the Building Materials and the Building Environment Divisions appear to have responded with positive action (hiring) to the panel's discussion of how using technicians to run and maintain equipment can increase the productivity of research staff and potentially improve the condition of the instruments. As discussed above, the laboratory as a whole continues to improve internal communications, and the formation of the junior advisory board, as suggested in last year's report, is a good element of this effort. The panel is also particularly appreciative of the laboratory's willingness to share with the panel the wide array of information needed for the assessment, such as project plans and milestones.

In certain areas, BFRL has indeed been responsive to panel recommendations, but more work is needed. As mentioned above, one example of such an area is laboratorywide strategic planning, where the first step has been taken. Other areas, such as internal communications and management of external funding decisions, are long-term issues that the panel expects to revisit regularly. In communications, the panel is certainly pleased with the progress made by the laboratory, but upcoming events such as the refocusing on homeland security activities, the planned merger of the Structures and the Building Materials Divisions, and development of a strategic plan will require constant and continuing effort.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- 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.
- BFRL could increase the impact of its work by focusing on the most important strategic objectives and priorities. The laboratory has taken the first step toward the development of a strategic plan. The next steps include sharpening the vision for the future of the laboratory, developing a comprehensive set of strategies and tactics to achieve this vision, and defining clear goals and metrics for success and accountability. An outside facilitator should be utilized to assist in integrating input from laboratory staff and external customers.
- 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 laboratory has an initial outline for how it can contribute in this area. 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 associated with a large, multiorganization project, and new skills and people will be needed for this task.
- 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 be prepared to propose construction of a state-of-the-art facility for fire testing of structures under load as part of the homeland security effort and to 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 at the laboratory level is needed, as are staff expertise and time that can be devoted to the process of getting this work adopted into regulations and actual use.
- The planned merger of the Structures and the Building Materials Divisions is an opportunity for the laboratory to build a unit that can lay the groundwork for a future in which materials are engineered to meet specific structural performance requirements. The panel is supportive of this ambitious goal but cautions that leadership and communications will be critical in combining groups with different cultures and different customers.

DIVISIONAL REVIEWS

Structures Division

Technical Merit

The mission of the Structures Division is to promote construction productivity and structural safety by providing measurements and standards to support the design, construction, and serviceability of constructed facilities.

The panel is impressed by the quality of the individuals in the Structures Division, the recognition they receive, and the high morale observed in the division this year. The Structures Division supports the BFRL goal of Advanced Construction Technology, with work occurring in two areas: Construction Integration and Automation Technology (CONSIAT) and Construction Systems and Safety (CONSAFE). The division is organized in three groups: the Construction Metrology and Automation Group (whose projects contribute to the CONSIAT area) and the Structural Evaluation and Standards Group and the Structural Systems and Design Group (both of which support the CONSAFE area). The panel is impressed by the broad array of projects in this rather small division and discusses the work under way in the two areas, below.

CONSIAT Program. The CONSIAT Program is carrying out much-needed, visionary, and excellent work that supports the broad trend among progressive facility owners and contractors to transform the construction of facilities and infrastructure from the current, unreliable, on-site production process of constructing a facility from many individual parts and components to a design-manufacture-assemble process that promises to be vastly more productive, safer, and more predictable. In light of the small size of the Construction Metrology and Automation Group (four technical staff, including one contractor), the contributions of the group are astounding.

The work on next-generation laser detection and ranging is one example of a project that particularly impressed the panel. This work is focused on the use of LADAR for range imaging metrology, and the division staff are taking advantage of hands-on experience with current, high-precision LADARs in the evaluation of LADAR technology for autonomous mobility applications. This work is appropriate and productive, although the panel does believe that it might be improved somewhat if the LADAR work could be related more clearly to other positioning technologies. Other noteworthy projects include the testing of innovative steel connections, the establishment of national calibration standards for laser equipment that will lead to traceable calibrations, and the development and testing of protocols for wireless, on-site communication.

The group's methods include a healthy and appropriate mix of applications, trials of new technologies, and laboratory and field work. There were, however, a few areas in which the panel thinks that the portfolio of projects could be strengthened. For example, heavy emphasis is placed on automation of steel construction. Why is there no work on the automation of construction with concrete, precast, and other construction materials? In another area, more work should be focused on determining metrics for the quality of the many types of computer models used for construction. No useful metrics exist today. Therefore, construction clients cannot specify how computer models should be delivered to them, and they cannot test how accurate the models are, which leads to the repetitive, wasteful, and error-prone re-creation of electronic information when it is needed. Finally, the activities would benefit from even more integration and synchronization of this division's work with the projects under way in the Fire

Research and the Building Environment Divisions; these divisions have relevant expertise in communication and modeling standards.

Overall, the CONSIAT Program is the shining star of the Structures Division; it shows how NIST can go beyond the basic mission of providing metrics, performance measures, and calibration services and can take the lead in performing some longer-range and higher-risk research and technology development.

CONSAFE Program. The CONSAFE Program contains a wide variety of projects, including work on next-generation standards for wind loads, performance of structural control systems, fiber-reinforced polymer (FRP) composites in construction, and measurement research for concrete testing standards. One noteworthy project is the work on using infrared thermography to perform nondestructive evaluation of the integrity of FRP laminates bonded to concrete and masonry. This project exemplifies exactly the sort of work that NIST should be doing, as it provides the basis for research and applications of this technology. The proposed work on new concrete testing standards should also be encouraged, although the panel would like to learn more about what new approaches should or will be taken and what the deliverables will be.

Other projects include the work on disaster resistant housing. The scientific basis for this project is not clear to the panel, nor is it clear whether industry will support such work. If a serious effort in this area is truly desired, the vision for a much more comprehensive program will have to be defined; such a large program would have great potential for external funding from FEMA, the U.S. Department of Housing and Urban Development (HUD), and Foreign Aid.

In the work on FRP composites, the division has important expertise but is currently focused on developing a retrofit concept, as are many other research groups. The panel believes that the NIST capabilities could be more productively directed toward providing leadership on metrics and performance evaluation. Similarly, the research program on semiactive control does not currently seem to have a unique focus. While there will always be new technical developments (e.g., shape memory alloys and magneto restrictive sensors and actuators), if the Structures Division wishes to pursue a program in this area, the work should be geared toward providing assessment tools and standards for new technologies.

In addition to the activities described above, the CONSAFE Program also includes the division's ongoing activities and expertise in performance-based fire engineering for steel structures, fire performance of high-strength concrete, and mitigation of progressive collapse in buildings. These are all critical areas for BFRL's planned homeland security work, and the Structures Division has a unique opportunity to take a leadership role among federal agencies in addressing these issues post-September 11. In light of this opportunity, it may be the right time for several of the more mature projects in the CONSAFE area to be brought to a meaningful conclusion and the efforts in the groups redirected toward the structural fire and safety issues.

The plans for Structures Division activities in response to the events of September 11 were still in a somewhat preliminary stage when the panel visited in early 2002. While the goals of the investigative phase of NIST's work were relatively clearly defined, a comprehensive plan to take advantage of BFRL's unique combination of expertise (in structures, fire, and materials) will be needed. Areas of opportunity include work to support the development of codes and standards that will prevent progressive collapse and improve fire safety and work on distributed sensor networks that could monitor structural and occupant behavior and safety. In particular, a long-term strategy for how to develop a performance-based fire code would be an excellent contribution to improving the safety of the nation's constructed facilities.

Vision for the Future

The panel is anticipating significant progress in the next year on the overall vision and plan for the Structures Division and for BFRL as a whole. The long-range plan or vision for these organizations needs to be better formulated and more clearly presented. For example, from the presentations it heard, it was not clear to the panel where the Structures Division sees itself in 10 years and what it needs in terms of funding and human resources in order to get there. The division's mode of operation is still much more geared toward asking "What can we do with our current staff and resources right now and over the next year or two?" than toward asking "What is our charge and what is it we would like to be recognized for in 10 years?" The Structures Division has the potential to impact and standardize the ways in which electronic models, construction processes, and constructed facilities are measured and thus to improve the economy and safety of all constructed facilities. An explicit vision and an implementation plan for the division and its groups should build on the potential impact of the division's work on education and on industry and should lead to an ability by the laboratory to articulate the resources needed to carry out their ambitious goals.

One way in which a clearer vision might help the Structures Division improve its programs is in improving the focus on projects and activities in which NIST can make a unique contribution. In several areas, the panel believes that the work under way in the division is not sufficiently distinct from projects that might be occurring as productively or more so in a university setting or in industry. Examples include the current conception of the enhanced object recognition work, some elements of the progressive collapse work, the semiactive control work, and the FRP retrofit concept. The division has stated that its goals include "to move more towards scientific research" and at the same time "not to compete with university research." The panel believes that these two statements are not compatible and that the division's intent needs to be further clarified. Focusing on work that can only be done at NIST will be critical as the division develops programs in fire integrity of structures, progressive collapse, distributed sensor networks, and health monitoring of structural systems to address issues raised by the attacks of September 11. In all of these areas, it should be clear that NIST's main mission is to define metrics and to provide guidance for relevant codes and standards; the primary mission is not performing basic research.

A significant factor in determining the future direction of Structures Division programs will be the proposed merger of the Structures and the Building Materials Divisions. The panel supports this merger because it will improve the size and visibility of both groups[4] and the combination of the expertise in these areas will allow BFRL to pursue a vision for construction in which both materials and structures can be engineered for specific applications.

Program Relevance and Effectiveness

In last year's assessment report, the panel suggested that the interactions of the Structures Division with industry could be strengthened, both to develop better access to input from industry about its needs and to increase the dissemination and use of division results. The panel is pleased to report that improvement was observed in this area. For example, the work with FIATECH on the Capital Projects Technology Roadmap is excellent. This project fills a critical need to synchronize the work of indus-

[4]A division produced by the merger would have a total staff of about 40 people and a budget of approximately $10 million, which would make it roughly equal in size to the Building Environment and the Fire Research Divisions.

trial, academic, and government laboratories, and the goal of integrating business planning with facility planning is particularly worthwhile. The value to the industry is clear, although the panel was not certain how the road map will be used to guide NIST research.

Another good outreach effort is the division's work on organizing and hosting the International Symposium on Automation and Robotics in Construction in September 2002. This conference is an important international meeting, and NIST's support of it is a worthwhile activity and a good service for the relevant professional and academic communities. The division staff also serve construction-related communities through a variety of committee activities, which help keep the staff in touch with the ongoing research and concerns of other professionals and academics in their fields and provide information about division projects in those fields. The Construction Metrology and Automation Group also has a very informative Web site.

Workshops and conferences are an important element of productive interactions with external communities, but other outreach activities will be needed to really connect with industry. Structures Division staff will also need to be able to describe the NIST programs to industry in such a way that the value and relevance of the work are clear. For example, what are the short-term and long-term goals and deliverables for the program? What can the division provide for the construction industry right now to show that it is developing meaningful technology? The road-mapping exercise mentioned above could be a first step in this direction if it not only identifies enabling technologies but also shows, in a credible and reproducible way, what the costs are of not having particular metrics and measurement standards. This information could then lead to a research agenda with improved coordination and prioritization and clearer economic benefits. As the Structures Division works with industry on this road map, the participants might benefit from looking at the International Technology Roadmap for Semiconductors as a model; this road-mapping exercise is industry-driven and well established and has a section on Factory Integration that may be relevant. The goal would be for the FIATECH/NIST road-mapping participants to build from this type of model to develop similar, more explicit road maps for other sectors of the construction industry and ultimately to learn how to develop and update these road maps to enable a systematic and sustainable process of technology innovations.

One area in which further strengthening of interactions with industry will be critical is CONSIAT. This program could have an enormous impact on the U.S. construction industry. The construction industry is on the verge of radically changing how facilities are designed, built, and managed. The combination of advanced materials (higher-strength traditional materials and new composites) with computer-based modeling techniques and capabilities for automated fabrication of customized components and systems makes it possible to move from mostly craft-based, on-site production processes with poor process reliability and safety to a design-manufacture-assemble process that minimizes on-site production and improves product and process quality, economy, and safety. The impact on the time and cost needed to develop and deliver a facility might be dramatic (some say that a 30 percent reduction in design-construct time and cost could be achieved easily); such cost reductions would not only strengthen the U.S. economy but would also contribute positively to worldwide development. A critical bottleneck in the migration from today's craft-based processes to more systematic and automated processes is the lack of measurement standards in virtually all aspects of construction (i.e., industry lacks the ability to assess the quality of a three-dimensional electronic model or to measure work completed in a rapid or consistent way). The Structures Division's work can play a critical enabling role in this area.

But for the division's impact to be felt, buy-in from the construction industry is absolutely essential. Verbal support from industry is not enough; companies must indicate their willingness to embrace new technologies by demonstrating real fiscal investments in the necessary equipment and research. The division's research is in an advanced state, but without a dissemination plan that clearly indicates a path

TABLE 7.2 Sources of Funding for the Structures Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	3.1	2.8	3.3	4.0
STRS, nonbase	0.4	0.0	0.0	0.0
ATP	0.1	0.1	0.1	0.0
OA/NFG/CRADA	0.3	0.5	0.5	1.2
Total	3.9	3.4	3.9	5.2
Full-time permanent staff (total)[a]	21	20	20	20

NOTE: Sources of funding are as described in the note accompanying Table 7.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

for adoption of these new technologies, the potential value of the NIST work will go unrealized. A key step would be establishing a highly visible and broadly publicized test project to provide an early demonstration of the advanced capabilities.

Division Resources

Funding sources for the Structures Division are shown in Table 7.2. As of January 2002, staffing for the division included 20 full-time permanent positions, of which 18 were for technical professionals. There were also 7 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The funding situation in the Structures Division has improved significantly in the past 2 years. In FY 2002, the division will be fiscally solvent for the third year in a row, and several factors are likely to strengthen the division's financial position in the future. One is the signing on April 1, 2002, of an MOU that designates NIST to serve as a research and technical resource for FEMA. This establishment of a formal relationship between the agencies has been in the works for several years, and the panel applauds both parties for finalizing the arrangement. The relationship should be a steady source of financial support for the division and should also provide a good dissemination route for NIST results. In return, FEMA will have access to high-quality, technically based advice and tools.

Another factor likely to strengthen the division's financial position is the proposed NIST initiative in homeland security. Funding for this program was being considered in Congress at the time of the panel meeting, and the proposed size of the overall program (roughly $40 million for a broad range of activities, including structural fire protection, human behavior and response, and building vulnerability) is significant. The funds would be distributed throughout NIST and would also support contracts with external institutions, but the expanded homeland security work certainly will be expected to have a noticeable impact on the Structures Division's resources. The panel notes that the division will have an important role to play in the management of contracts with outside organizations, particularly in the World Trade Center investigation effort, and resources for specialized contract management personnel and functions will have to be allocated so as to avoid extra burdens on division staff, who are best qualified and suited for technical activities.

While the Structures Division is certainly more stable financially now than in the past, some concerns remain, particularly with respect to decisions about external funding. Outside support is uneven in the division; the CONSAFE program receives 25 percent of its funding from external grants, while the CONSIAT program gets practically no money from outside. It appears to the panel that the acquisition of often small outside projects is done in a somewhat haphazard way and that funding is sometimes pursued without an analysis of whether the size of the grant is worth the effort of winning it or whether the tasks other agencies are willing to fund appropriately complement division goals. The division should consider a more strategic approach to acquiring outside contracts and integrating those projects into its programs.

The panel is impressed by the sheer number and variety of research programs with which this small division is involved. More and new opportunities are continually arising (particularly in the response to the September 2001 events), and the panel is concerned that further fragmentation of research efforts may occur, leaving many projects below critical mass. Already, the Construction Metrology and Automation Group is seriously understaffed, although efforts are ongoing to hire three more people for this group. However, given the potential impact on the safety and economy of construction throughout the United States, even doubling the staff of the group would still be inadequate. This issue is particularly serious, as the efforts being proposed by NIST and this panel for homeland security may even divert resources from the construction metrology and automation work.

As discussed in previous sections of this chapter, a key element of the homeland security work in BFRL will be work on the safety and performance of structures in fires. BFRL has the expertise in the Structures and the Fire Research Divisions to tackle this complicated problem, and in the Large Fire Research Facility the laboratory has the base on which the necessary state-of-the-art testing facility could be built. While significant improvements to this facility have been considered in the past, a new effort will be required to develop an up-to-date description of the capabilities that would be necessary in the context of post-September 11 needs. The goal for any upgrade of this facility should be for NIST to have the leading structural fire test research laboratory in the world. A vision for this facility—what it should look like, what the real test objectives are, and what the development and implementation strategies are—will be needed in order to determine the cost of developing the facility and to argue convincingly for its funding.[5] This effort will require close cooperation between the Structures and the Fire Research Divisions and the laboratory office. If BFRL is not able to present an exciting and bold vision for a program and facility in this area and a plan to execute that program, NIST may not receive the resources it needs and deserves to support work on improving structural fire safety.

Other resources-related issues from last year's assessment report included internal communications and maintenance costs of large equipment. In the first area, the panel noted distinct improvement due to concerted efforts on the part of management and staff; the establishment of a junior advisory board has also helped. Maintenance of large equipment was less of an issue this year, as the universal testing machine is seldom used, and the tridirectional testing facility is being upgraded.

[5]A budget derived from proposals from several years ago was presented to the panel, which found the estimated costs definitely insufficient to develop a state-of-the-art test facility.

Building Materials Division

Technical Merit

The mission of the Building Materials Division is to develop test methods and predictive tools for next-generation construction materials. Progress toward this clear overall goal is accomplished through careful and thoughtful analytical, laboratory, and field work based on science from a variety of technical disciplines. By developing the scientific bases for the performance and longevity of construction materials, the division is actively improving the criteria and standards used to evaluate, use, and maintain construction materials and ultimately will improve the ability of end users to select appropriate construction materials such as high-performance concrete, coatings, and sealants. The strength of the division is its establishment of the fundamental underpinnings of the performance of building materials. Its work is based clearly on firm principles of materials science, which is an interdisciplinary field combining many elements of chemistry and physics and certain elements of engineering and economics. This interdisciplinary expertise makes the division well suited to contribute to joint projects with other BFRL and NIST groups, and division management highlighted for the panel numerous collaborative relationships with researchers both within NIST and at universities.

The Building Materials Division is responsible for BFRL's major goal of High-Performance Construction Materials. Work on this goal is divided into two programs: high-performance concrete technology (HYPERCON), which is the responsibility of the division's Inorganic Materials Group, and service life prediction of high-performance polymeric construction materials, which is led by the division's Organic Materials Group. Also located within the Building Materials Division is the Construction Materials Reference Laboratory (CMRL), which is managed by the American Association of State Highway and Transportation Officials (AASHTO) and contains the ASTM Cement and Concrete Reference Laboratory (CCRL) and the AASHTO Materials Reference Laboratory.

The research carried out by the Building Materials Division staff is generally of excellent quality. The panel continues to be impressed by the focus of the work and by the division's ability to maintain that focus even while expanding the work into new projects in related areas. The equipment available to the staff is, for the most part, very good, and some of the instrumentation in the division is clearly state of the art, such as the integrating ultraviolet (UV) sphere in the Organic Materials Group and the x-ray moisture profile measurement system in the Inorganic Materials Group. The staff take full advantage of the existing equipment, and the experiments under way appear to the panel to have been well considered and carefully planned, which is important considering the complex and long-term nature of the projects.

Inorganic Materials Group. The Inorganic Materials Group coordinates the projects supporting the HYPERCON Program, which is aimed at measuring, understanding, and predicting the performance of high-performance concrete (HPC). The work under way has clear objectives and includes investigations on the fundamental characteristics of HPC in both the liquid and cured solid states. This group has what may be the world's best program on the computational materials science of concrete, and the quality of the group is evidenced by its development of the VCCTL, a menu-driven virtual testing laboratory. Users can input basic information into fill-in forms, and the software then provides predictions of cement and concrete properties based on detailed microstructural simulations of well-characterized starting materials. Properties that may be predicted include setting times and degrees of hydration to achieve set, chemical shrinkage, and compressive strength development.

VCCTL's success clearly reflects a good basis of computational and theoretical work in this group, but it also rests on a series of good experiments. For example, the project on modeling transport in HPC seeks to develop a continuum service life computer model of ion transport in concrete beginning with basic experiments and progressing through work in molecular dynamics. Appreciation of the complexity of ion transport mechanisms in cement and concrete systems has grown over the past year; however, recent results suggest that regardless of how many or what kinds of ions may be present in a system, their movement can be defined by system porosity and a formation factor. Work on the mathematical characterization of particle shape using spherical harmonics is feeding directly into the VCCTL, as it will provide a way to account for particle assemblies and their interactions.

In other work to strengthen the underpinnings of VCCTL, modifications of its hydration module have been made through experimental, modeling, and simulation work. Particle shape is believed to strongly influence cement and concrete rheology, and models developed to predict elastic properties of cement pastes have been validated through comparisons with experimental measurements of the properties of pastes and their components.

The efforts to characterize concrete in its liquid state have produced some excellent rheological work on fresh concrete and cement. Milestones achieved this year include the development of a model for predicting relative viscosity from coarse aggregate gradations, measurements of mortar properties, simulation of specific practical flow situations, incorporation of results into VCCTL as tools for prediction, and performance and publication[6] of an international comparison of concrete rheometers.

The project on characterization of the microstructure of cements and concretes continues to provide key results and to build strong capabilities in support of the entire HYPERCON Program, as well as of VCCTL. Progress continues to be made on developing improved materials characterization tools such as Rietveld analysis that will assist in valid performance prediction. This past year the laboratory participated in a round-robin evaluation of two CCRL cements using techniques of particle size distribution analysis and scanning electron microscopy/energy dispersive x-ray analysis. A 3-year project on the sulfate resistance of cements in concrete, funded by the Portland Cement Association, is wrapping up after having established a new approach to cement selection that is based on performance and aging criteria. Among this project's accomplishments are the development of an ASTM sorptivity test that is now in ballot, a relevant database cataloging details of test specimen deterioration, and a better understanding of reaction chemistry and kinetics in blended cements.

Organic Materials Group. In the Organic Materials Group, the focus on service life prediction continues to provide a strong theme around which all programs are organized. In a field where much empirical work has been and is still being done, BFRL's service life prediction projects take a scientific approach to understanding durability by seeking to identify the real metrics of performance degradation and its fundamental causes and effects. The Organic Materials Group currently is conducting a number of interconnected projects that capitalize on the group's core competencies. Much of the work is addressed through three ongoing consortia—Coatings Service Life Prediction, Interfaces and Interphases, and Service Life of Building Joint Sealants—and, in addition, a significant new research effort in nanometrology was launched in 2001.

A long-standing project on coatings durability has moved into the first year of its third 3-year phase with continued industrial support from the Coatings Service Life Prediction Consortium. This ambi-

[6]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Comparison of Concrete Rheometers: International Tests at LCPC (Nantes, France) in October, 2000*, NISTIR 6819, National Institute of Standards and Technology, Gaithersburg, Md., September 2001.

tious project seeks to relate outdoor exposures tests to tests done under accelerated laboratory conditions relative to degradation of epoxy coatings. Principal environmental factors studied have been relative humidity, temperature, and UV dose. In the laboratory, UV dose will be delivered using BFRL's unique UV integrating sphere, a patented device that uniformly delivers up to 17 suns of UV light to several exposure ports simultaneously. BFRL has designed and built at least three different versions of humidity and temperature controls for the sphere and believes that the most recent will be the one that works for the long term. Both chemical and microscopic surface features are being examined in this work using analytical tools that directly obtain the chemical and microstructural information needed. Many coatings involve the chemical formation of a network, and work is being done to correlate changes in the rubbery plateau and glass transition temperatures of the examined coatings using dynamic mechanical analysis. For the analysis of the large volumes of data generated in this project, the researchers have wisely collaborated with a statistics expert from NIST's Information Technology Laboratory as well as with an academic expert in statistics from Iowa State University. As this project moves into what is expected to be its final phase, attention is turning to the use of modeling to allow application of the project findings to non-epoxy coating systems. It is anticipated that the Organic Materials Group will draw from the Inorganic Materials Group's expertise in modeling for this work, but it will also need to enlist other collaborators for the creation of viable models related to organic polymeric materials.

The two newer consortia are also moving ahead in their work. One of these, the Interfaces and Interphases Consortium, has completed its first year with its three initial sponsors and has recently added a fourth supporter. This consortium is a joint effort between BFRL and NIST's Materials Science and Engineering Laboratory (MSEL) and Chemical Science and Technology Laboratory (CSTL). BFRL's portion of this project lies in the characterization of the surface mechanics of polymeric materials, with an emphasis on scratch and mar resistance. A critical tool in the project is a recently acquired nanoindenter, the first at NIST, which will be used to characterize interfaces and interphases as well as surfaces. This work will also utilize the group's light scattering facility for the characterization of surfaces damaged by mechanical deformation. Modeling of viscoelastic behavior will be done to relate materials properties to deformation behavior under complex stress states. The effect of the imposition of deformation scales from the molecular to macroscopic levels on the appearance of polymeric materials will be assessed by means of a variety of useful direct methods. A key tool will be a recently built laser scanning confocal Raman microscope that will allow for surface and subsurface textural and chemical study.

The newest consortium in the Organic Materials Group, the Service Life of Building Joint Sealants Consortium, got under way in October 2001 with the support of nine corporate members, the Forest Products Laboratory, and HUD's Partnership for Advancing Technology in Housing. The Building Materials Division project in this area is focused on developing relationships between UV dose and the loss of sealant effectiveness as indicated by modulus changes. Other important environmental exposure parameters include moisture, temperature, and load. While this project will use many of the same methods developed in the work on service life prediction for coatings, it will also look at how UV exposure under mechanical load accelerates aging.

The project on appearance, a 5-year multilaboratory effort, was brought to a close after achieving its primary goals and a few months before the retirement of its principal investigator in January 2002. This project appears to have been well thought of within NIST, particularly owing to the quantity and effectiveness of its interlaboratory collaborations. The project succeeded in developing a procedure for predicting optical scattering from materials formulation and structure data that supports product design, material processing, and rendering. Staff were able to create excellent three-dimensional renderings of objects coated with a clear coating and a metallic-flake pigmented coating, dealing with predominantly surface scattering in the first case and subsurface scattering in the second. A scattering-based method of measuring gloss was developed, and thus a fundamental foundation was established for the gloss meter that has been widely used in industry for decades. The technical competencies developed in BFRL over the course of this project are being applied to other relevant efforts, and some group staff will continue to take note of and participate in activities in the appearance area.

As the appearance work has wound down, a new set of projects on nanometrology has begun. This work is motivated by a perceived need for better understanding of the dispersion and photocatalytic behavior of particulate microscopic and nano-sized metal oxide materials used as pigments in building materials. In one part of this activity, the scattering expertise and instrumentation developed through the appearance work will be utilized and expanded in a project aimed at characterizing structure and pigment dispersion in polymeric building materials. Coatings and some other building materials are highly pigmented, and industry predominantly uses a variety of indirect characterization methods that are useful but qualitative or subjective, and direct methods that are of limited use, require much time and complicated analyses, and are destructive in nature. The methods developed in this project will be applied to both cured and uncured polymeric systems, the ultimate goal being the development of a new, nondestructive in-line dispersion characterization method that will not be limited to dilute systems as current commercial methods are. The materials systems studied will contain titanium dioxide (TiO_2) or zinc oxide (ZnO) pigments. A second project related to pigment dispersion is a new effort in the characterization of the photocatalytic activity of nanoparticle pigments in building materials. These pigments have different activity and effectiveness depending on their size, which in many cases is dependent to some extent on their degree of dispersion. The project seeks to establish the basis of the general photocatalytic activity of such pigments by looking at the generation and conduction of electrons in pigmented materials.

Finally, one more project appears to be winding down. The division has basically put its work on fiber-reinforced polymer/plastic composites on the shelf for the time being. This project sought to develop a standard for polymer-based composites based on load and resistance factor design (LRFD); such standards already exist for steel, wood, and concrete. While strong interest in this work existed and BFRL was uniquely positioned to carry out the objective, the division found that industry was not fully converted to the need for LRFD standards for composites. The reasons for this are rooted in economics, in the lack of widespread use of composites in major stationary structures, and in the continued specialty status of composites. It is perhaps telling that there are no longer any structural composites projects of great significance anywhere within NIST; however, many of the materials studied in the Building Materials Division actually are composites in the generic sense of the term.

Proposed Building Materials and Structures Division Merger. A major issue for the Building Materials Division is the ongoing discussion of its proposed merger with BFRL's Structures Division. The large new division will support the BFRL goals related to materials and construction, and the merger is expected to strengthen the divisions' abilities to serve their industrial customers. Though a number of distinct differences exist between the two divisions, they share some important similarities, and their combination could support an ambitious vision of collaboration between engineers dealing with macrostructures and physical scientists focused on microstructures. It is reasonable to expect that in time the technical focus of the new division will evolve to something more than and different from a simple combination of the two divisions' organizational charts. Areas identified as possible new opportunities, some with significant potential for technical synergy, include robotics, high-throughput analysis, automation, and smart materials and intelligent sensors.

The process of merging the divisions is proceeding slowly and carefully. The current chief of the

Structures Division was asked to organize a task force late in 2001 to address the merger, and the task force's preliminary report was completed in February 2002. The new division, tentatively named the Materials and Construction Research Division, is expected to come into formal existence in October 2002 (the start of FY 2003). The long-time chief of the Building Materials Division retired at the beginning of 2002, and the very capable leader of the Organic Materials Group will be acting division chief until the merger takes effect.

The panel expects that the first year of the new division's life will be marked by the growth of these two rather different divisions into a coherent unit in name, spirit, goals, programs, and organizational structure. The Building Materials Division has a comparatively young staff and takes a science-based approach in its work, about 40 percent of which is funded by outside sources. The Structures Division, on the other hand, has a more mature staff, which is engineering-oriented in its work, and is largely internally funded. This year's panel is not in a position to predict the outcome of this merger, although next year's assessment will certainly include an evaluation of the impact of the changes. However, it is clear that this merger will be a time of significant transition for the staff and the programs in the Building Materials Division. While personnel have been assured that there will be no headcount reductions as a result of the merger, many other uncertainties remain, and division and laboratory management should make a concerted effort to keep staff up to date on the progress of the merger and the status of various key decisions.

Program Relevance and Effectiveness

The projects under way in the Inorganic Materials Group include investigations that span the full range of cement and concrete use, from the raw materials of which they are made, to the methods of combining and mixing them, the means of using the compounds, and the question of their longevity. Customers for this group's results are quite diverse, including industry, government, and academia, and the collaborations under way reflect this breadth. The VCCTL Consortium has eight industrial members, including two new companies added this year, and these members' support of the division programs clearly demonstrates their approval of the topics that the group chooses to study and their faith in the group's past and future ability to produce results. The U.S. Nuclear Regulatory Commission is particularly interested in the group's projects relevant to the use of concrete as an entombment material for decommissioned nuclear reactors. The group collaborates effectively with all of the other BFRL divisions and its Office of Applied Economics, as well as with other NIST laboratories (ITL, MSEL, and CSTL). Academic partners include the University of Illinois and Northwestern University, which are members of the Center for Advanced Cement-Based Materials. Guest researchers also play an important role in group activities; five were in the laboratories in early 2002, and five more were scheduled to come in the middle months of the year. These researchers represent four different countries. The Inorganic Materials Group personnel are active in a number of professional societies and standards committees. Staff serve on more than 24 committees of the ASTM, American Concrete Institute (ACI), RILEM,[7] and International Center for Diffraction Data as chairs, vice chairs, secretaries, and members. In spite of all these commitments, staff also produced 36 publications and conference papers as part of the HYPERCON effort in 2001.

[7]RILEM is the International Association for Building Materials and Structures; RILEM is the French acronym for Réunion Internationale des Laboratoires d'Essais et de recherche sur les Matériaux et les Constructions.

A major product of the Inorganic Materials Group is the VCCTL. By helping concrete formulators to eliminate formulations likely to miss their target, VCCTL can gain for concrete producers the time and cost savings needed to do only the physical testing that is really necessary. Version 1.0 of VCCTL is available on the Internet;[8] in recent months, it drew 60,000 users from 60 countries. The VCCTL has also received a good share of attention recently from the building materials industry in articles published in *Civil Engineering*, *Engineering News Record, The Concrete Producer, Concrete Construction,* and *Contractor.* Articles in these trade and technical magazines publicize VCCTL among the building materials suppliers, who are the VCCTL's primary customers. This long-term project recently completed the first year of a 3-year consortium effort that is aimed not only at improving the capabilities of the VCCTL but also at proliferating its use beyond the research community of the cement and concrete field.

The service life prediction projects of the Organic Materials Group are clearly important to BFRL's customers, as the group's three consortia involve a total of 21 members, most of them industrial producers of building materials. In addition, representatives from the roofing asphalt industry have been asking recently about the establishment of a consortium that would serve its needs in service life prediction. The work on composites has been stopped for the time being for want of full industrial participation, but the panel believes that this work has relevance for industry nonetheless.

The relationships between the Organic Materials Group and its three consortia are very strong. This connection not only allows the group to have access to sustained financial support but also provides group staff with information about industrial approaches to project management. For example, the panel notes that staff are increasingly using Gantt charts and other scheduling tools to track the progress of consortia-supported work according to specific time lines. The use of these tools is being driven by the consortia members, who use the tools themselves for their own internal projects.

In addition to the industrial partners in the consortia, the Organic Materials Group collaborates with a variety of researchers at a number of institutions. The group has productive collaborations with five other NIST laboratories (Physics Laboratory, MEL, ITL, MSEL, and CSTL), and 17 guest researchers have been associated with the group over the past year; these guest researchers bring outside information into the group and take its findings out to industry and academia. Other dissemination mechanisms include helping to organize the second international Service Life Prediction Symposium in 2001 and 30 publications in journal and conference proceedings in 2001.

Organic Materials Group staff are very active on ASTM committees as chairs, secretaries, and members of 14 committees. Standards committee work is particularly important for the group's four projects targeting the analysis and abatement of lead-based materials. These projects are funded by HUD and have resulted in the development of more than 25 standards, in part through participation in ASTM Subcommittee E06.23. Several states in the eastern United States already are citing the ASTM standards for remediation of lead-based paint, and over the past year HUD has begun to cite the ASTM standards in its regulations.

The effectiveness and impact of the Building Materials Division programs are a product of the excellence of the division staff and are reflected in the recognition that staff members receive from external communities. In the past year, division personnel have been honored in a variety of ways. Awards received by individual staff members include the 2001 John C. Weaver Excellence in Leadership Award from the ASTM Committee D01 on Paint and Related Coatings, Materials, and Applica-

[8]The VCCTL is available online at <http://ciks.cbt.nist.gov/vcctl/>.

tions; the 2001 Walter Voss Award from ASTM for notable contributions to "knowledge in the field of building technology, with emphasis upon materials" for work in lead-based paint abatement; election as a fellow of the American Ceramics Society in recognition of pioneering contributions to the computational materials science of cement and concrete; and the Distinguished Chapter Member Award from the National Capital Chapter of the American Concrete Institute for 2000 for exceptional contributions to the chapter and to ACI. Staff also serve in key roles in professional societies; one recently retired staff member (now a guest researcher) was elected to the ACI board of directors, and another recently retired staff member (also now a guest researcher) was elected to the board of governors of the Intersociety Color Council.

Division Resources

Funding sources for the Building Materials Division are shown in Table 7.3. As of January 2002, staffing for the division included 21 full-time permanent positions, of which 18 were for technical professionals. There were also 4 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The panel is impressed by the quality of the staff in the Building Materials Division and by their enthusiasm for the division's activities, which remains high even as the researchers mature. The division is not deeply staffed, relying heavily on specific individuals for progress in each of its project areas. To supplement its core personnel (8 full-time persons in the Inorganic Materials Group and 11 in the Organic Materials Group), the division relies on extensive collaborations, as described above, and non-permanent staff. For example, the division effectively utilizes guest researchers, who are an important source of high-quality labor, technical expertise, and intellectual collaboration. The current group of guest researchers includes visitors from other institutions, as described in the previous section, and recent NIST retirees. The recent retirees often provide essential expertise (e.g., one retiree is

TABLE 7.3 Sources of Funding for the Building Materials Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	1.8	1.8	1.9	2.7
Competence	0.2	0.2	0.2	0.0
STRS, nonbase	0.1	0.1	0.1	0.0
ATP	0.1	0.1	0.1	0.0
OA/NFG/CRADA	1.8	2.2	1.5	1.9
Other Reimbursable	0.1	0.1	0.1	0.1
Total	4.1	4.5	3.8	4.7
Full-time permanent staff (total)[a]	21	20	20	21

NOTE: Sources of funding are as described in the note accompanying Table 7.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

supplying relevant and needed background in structure-property relationships of structural adhesives and composites for the Organic Materials Group) or perform key outreach activities (e.g., a retiree is continuing her participation on standards and color committees). Finally, a special guest researcher is the former division chief, who retired at the beginning of 2002. He will be continuing his important liaison work for BFRL with ACI, but the panel notes that his time as division chief was characterized by his ability to attract excellent researchers and to manage top-notch research programs as well as by his effective ambassadorship for VCCTL and the HYPERCON Program. He will be missed.

Students play some part in Building Materials Division projects, and kudos are due to two staff members who worked with the National Science Foundation (NSF) to establish a Student Undergraduate Research Fellowship program; as a result of these efforts, 11 undergraduate students spent the summer of 2001 in BFRL, where they gained valuable laboratory research experience. A program officer from the NSF is currently a guest researcher in the division, and, among his other activities, he is working to establish NSF graduate fellowships that would take place at NIST. Greater participation in division projects by graduate and undergraduate students would provide a high level of support for the division's full-time researchers, and these students, at their next jobs or institutions, would also help to disseminate information about the division's programs and results more widely.

Another potential source of additional expertise and support for division researchers is the research associates who staff the Construction Materials Reference Laboratory, organizationally situated within the division. Division management has indicated that a concerted effort is being made to better integrate the work of the CMRL staff with that of the researchers in the Inorganic Materials Group, and the panel strongly urges the division to continue this effort, as it should benefit both the division and the CMRL. At present, at least two CMRL staff members are involved with work in the Inorganic Materials Group's microstructure laboratory, and CCRL staffers routinely provide cement proficiency samples for group projects.

Given the tightness of human resources in the division, it is important to use the time of all personnel productively. In the past, the panel has emphasized the value of having sufficient technician support for the many instruments used in this division, as this allows the equipment to receive dedicated care from qualified individuals and allows the Ph.D.-level researchers to focus their time and attention on project design and investigations. Thus, the panel was very pleased to learn the Organic Materials Group had added a high-level technician in 2001 and was planning to add a master's-level analytical chemist for the service life prediction characterization laboratory in 2002 and that the Inorganic Materials Group was seeking a high-level technician to assist with the ever-increasing workload in its microstructure characterization laboratory. The panel applauds this emphasis on bolstering support staff.

It is not known whether or how the staff of the Building Materials Division may be asked to participate in the federal government's homeland security initiatives. Development of improved fire protection materials and bioactive filters are two areas to which it has been mentioned that division staff may contribute. It is the panel's opinion that the reassignment of any of the division's researchers to any homeland security projects would jeopardize the project objectives that make such excellent use of the division's core competencies. Unless the number of personnel was increased, progress in any one of these areas undoubtedly would be slowed.

The array of equipment in the Building Materials Division is very impressive. Recent new instruments or improvements in existing capabilities include NIST's only nano-indenter, the continued refinement of the light scattering facility, a variety of components for the 2-m integrating UV sphere, an x-ray absorption unit for a scanning electron microscope (SEM), a 32-processor computer, a pore press for HYPERCON, and an ion chromatograph. A particle size analyzer is scheduled to be installed in the near future. This division relies heavily on experiments, both for the fundamental insights that they reveal and for the inputs they provide to computational and theoretical models being developed at NIST. Staff are effectively utilizing the existing equipment, but several other instruments or instrument upgrades would benefit the programs. In the Organic Materials Group, the staff's "wish list" includes a clean room (needed to prevent the incorporation of particulates into coatings); a dynamic mechanical analyzer appropriate for rheological characterization of polymeric, as opposed to cementitious, materials; and a gel chromatograph/mass spectroscopy system for analysis of captured or directly generated volatile derivatives. In the Inorganic Materials Group, the staff would like to have a new SEM to replace an aging workhorse SEM, more computational power for modeling efforts, and a concrete laboratory to enable preparation and characterization work beyond mortars.

Building Environment Division

Technical Merit

The mission of the Building Environment Division is to optimize total 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 motto is "Assuring that buildings work better throughout their useful lives.") To achieve this mission, the division's work includes developing comprehensive, integrated approaches to information management that are capable of supporting a diverse collection of decision-making activities that span the entire life cycle of a building.

The Building Environment Division is responsible for work toward the BFRL goal of Enhanced Building Performance. In support of this goal, research, development, and demonstration work is carried out in the two program areas: cybernetic building systems, which involves two of the division's five groups (Mechanical Systems and Controls, and Computer Integrated Construction) and healthy and sustainable buildings, which involves the other three groups (Indoor Air Quality and Ventilation, Thermal Machinery, and Heat Transfer and Alternative Energy Systems). Below, the panel discusses the activities of each group.

Mechanical Systems and Controls Group. The projects in the Mechanical Systems and Controls Group are excellent examples of how NIST provides state-of-the-art technology research and development that is focused on real-world problems and industry needs. The group's internally funded activities occur in three primary areas: mechanical control systems, fault detection and diagnostics (FDD), and the Virtual Cybernetic Building Testbed (VCBT).

NIST is well known as an industry leader in support of standards for mechanical control systems. Building Environment Division staff were key drivers in the development of the BACnet protocol, which was adopted by ASHRAE and ANSI and is now being adopted by ISO. NIST has played a leadership role in BACnet development since the network's inception in 1987, and the leader of the Mechanical Systems and Controls Group is the current chair of the ASHRAE committee on the BACnet standard. Currently, the group's work on BACnet has gone beyond standards development to focus on development of the capabilities and infrastructure needed to promulgate the standard and ensure its appropriate use. For example, NIST personnel are involved in drafting test procedures for verifying a product's conformance with BACnet; this is a crucial activity, because the standard is so complex that it is difficult for customers to evaluate products on their own.

One new and appropriate project under way in the BACnet area is work on demonstrations of multibuilding networks of BACnet-conformant systems that can provide higher-level optimization and facility information. The group is working with the U.S. General Services Administration (GSA) on a demonstration project called GEMnet (for GSA Energy Management network). Currently, the technology is being demonstrated in 11 federal buildings in GSA Region 9 (the Pacific Rim Region). One benefit of such systems is that they will help building owners manage energy costs. This capability will make the technology particularly attractive to organizations such as GSA, which own and operate many buildings, and if influential owners such as GSA embrace the systems, other owners are likely to follow.

The second focus of the Mechanical Systems and Controls Group is on FDD, including building commissioning. Over many years, the division has performed strong work on the development and demonstration of algorithms for detecting faults in the mechanical systems of buildings, and where possible, identifying the causes. Staff served as the Department of Energy representative and country leader on the U.S. delegation to the International Energy Agency (IEA) Annex 34. The resulting exchanges with other domestic and international collaborators and industrial partners were very productive and provided the framework for the development at NIST of an FDD test shell and of specific FDD methods. The group has continued the work started in Annex 34 by further developing rule-based fault detection and diagnostic methods for detecting faults in air-handling units and statistical quality-control methods for detecting faults in variable-air-volume boxes. The former method was demonstrated at Montgomery College; the method worked well, detecting a number of faults, and the facility personnel were happy with the results. Several control manufacturers have chosen to incorporate the NIST algorithms in their controllers, which is certainly evidence that this is an appropriate and useful technology.

A significant next step in the FDD area is the group's entry into research on building commissioning. NIST staff—along with many other researchers—have realized that the first step in effective long-term FDD is to ensure that a building is operating correctly from the start and to establish an effective baseline of performance. The Mechanical Systems and Controls Group is again showing leadership by serving as the country lead for the U.S. delegation to IEA Annex 40 on building commissioning. If the group's successful technology transfer in the area of FDD can be replicated here, NIST will help drive industry in the United States and abroad toward adoption of this important technology.

The final area of activity for the Mechanical Systems and Controls Group is work on the VCBT, a multigroup (with the Computer Integrated Construction Group) and multidivision (with the Fire Research Division) project. The VCBT laboratory apparatus has played a crucial role in cost-effectively testing the performance of BACnet-compliant controllers. It has also been used as the basis for the early development and demonstration of concepts for technologies such as FDD and GEMnet and has proven useful in the development and testing of other technologies and algorithms from several divisions within NIST. For example, fire researchers have used the facility to develop, test, and demonstrate algorithms to support the Smart Panel, which provides first responders with detailed information about the development of a fire within a building. The VCBT has also been used by the construction automation researchers to demonstrate the integration of computer-aided design (CAD) drawings and construction data, controls, and operations.

Computer Integrated Construction Group. The major objectives of the Computer Integrated Construction Group are to work with the building and construction industry to establish a sound technical basis for seamlessly sharing information throughout the life of a facility; transfer the technology to industry through the development of consensus, open standards; implement and test exemplar software applications incorporating the standards; demonstrate the integration/interoperability of these and other applications in pilot projects; and provide validated test-case data sets and test metrics. Through work toward these objectives, the Computer Integrated Construction Group is making fundamental contributions to the Building Environment Division mission.

The Computer Integrated Construction Group is working on projects in two program areas: cybernetic building systems and construction integration and automation technologies. Projects within the cybernetic building systems program area include the development of product data standards for heating, ventilating, air-conditioning, and refrigeration (HVAC/R) systems, and an information infrastructure for the simulation of building performance under normal and adverse conditions. Projects within the construction integration and automation technologies program area focus on the development of product data standards for steel construction and for industrial facilities. These projects build on previous work done in the group.

In the past, the panel has expressed concern about coordination between the Computer Integrated Construction Group and the Construction Metrology and Automation Group of the Structures Division. Group management has emphasized that the overlap between group projects is limited to those projects relevant to the CONSIAT goal (i.e., the work on product data standards for steel construction and industrial facilities), and the necessary coordination appears to be occurring for those projects. The panel believes that the other work within the Computer Integrated Construction Group, particularly the projects focused on life-cycle information management, should be coordinated across BFRL divisions as well. Reorganization is not recommended, but for goals in the life-cycle information management theme to be fully and efficiently realized, the work will require a champion (perhaps the Computer Integrated Construction Group) that can broadly coordinate multidisciplinary work across divisions and other laboratories within NIST.

The goal of the group's project on product data standards for HVAC/R systems is to extend the International Alliance for Interoperability (IAI) Industry Foundation Classes (IFC) data model so that it can support decision making regarding these building systems throughout the life cycle of a facility. The panel believes that this work addresses a critical information requirement for improving the performance of buildings related to their energy consumption, indoor environmental quality, and response to emergency conditions (fire, contaminant dispersion, and so on). A key expected benefit of this project is the ability to capture HVAC/R design information for continued use in downstream commissioning and operations and maintenance activities. The project includes plans to implement and test the HVAC/R model extension in the context of the VCBT, which will allow staff to validate the model extension, increase their experience with implementation of IFC data import/export capabilities, and raise the visibility of IFC data interoperability through future VCBT demonstrations.

The work on developing an information infrastructure for the simulation of building performance under normal and adverse conditions results in part from reprogramming in response to the events of September 11. This project builds nicely on existing expertise and past results by integrating the product data standards work and the simulation tool CONTAMW[9] developed by the Indoor Air Quality and Ventilation Group. The plan is to develop a data mapping between the IFC data model and the CONTAMW internal data model, implement a translator based on this mapping, and test the translator by exchanging data between a CAD representation of the NIST Administration Building and CONTAMW. This implementation of interoperability between CAD and CONTAMW will then be used to conduct a study of likely adverse events in the building. The experience gained through this project will be applied to bring interoperability capabilities to other NIST simulation and analysis programs. This project will provide valuable feedback for improving and further extending the under-

[9]CONTAMW is a software package for multizone airflow and contaminant transport analysis. It is available online at <http://www.bfrl.nist.gov/IAQanalysis/CONTAMWdesc.htm>.

lying IFC data model, and it also contributes to the life-cycle information management theme being developed in this group.

The product data standards work in the construction integration and automation technologies program continues to go well. Recent accomplishments in the steel construction area include prototype implementation and validation of the CIMsteel Integration Standards (CIS2) and interactions with software vendors to test and correct their CIS2 translators. Next, the group will focus on harmonizing CIS2 with other evolving standards from ongoing ISO/STEP, IAI/IFC, and XML initiatives. These efforts are necessary to promote the successful adoption of the standards in the marketplace. Within the project on developing product data standards for industrial facilities, the STEP Application Protocol for process plant industries that was developed by NIST and other PlantSTEP Consortium members was formally approved as an international standard, thus validating the high technical merit of this work.

The panel believes that the current collection of projects under way in the Computer Integrated Construction Group is well conceived and well directed at the goal of enhancing and extending the product data standards that have resulted from previous work and at helping to promote the adoption of these standards in the marketplace through trial software implementation and pilot application to real-world building projects. Next it will be important for the group to move beyond the goal of formal approval of data model standards and focus on promoting the adoption of the standards within the marketplace. Trial implementation and highly visible, well-documented pilot demonstration projects are critical to getting the word out.

Indoor Air Quality and Ventilation Group. The Indoor Air Quality and Ventilation Group has displayed technical leadership in relevant fields for many years, but the events of the past year have underscored the importance of this area of study. The value of NIST's role as a provider of unbiased scientific information and analysis has never been clearer.

Airflow and pollutant model development is one key activity of the group. Staff have provided innovative, high-quality performance prediction methods for research, development, and design. The most widely used model created is the CONTAMW program, which performs multizone mass balance analysis to determine contaminant concentrations in zones over time. Once a model of a particular building is built, CONTAMW can be used for ventilation design, contaminant analysis, and smoke management. The group is currently working on further enhancing the program's modeling capabilities by integrating existing ventilation modeling with thermal and fire modeling programs. It is also working on improving usability by providing libraries of model inputs, different views of a building, integration with data from CAD systems, and postprocessing software for calculation and visualization. CONTAMW is freely available and can be downloaded from the NIST Web site. This program is a good example of how state-of-the-art basic research can produce practical tools useful to industry. It is also a good example of intralaboratory collaboration, as researchers from the Computer Integrated Construction Group and the Fire Research Division have made important contributions to the project.

In the work on ventilation and indoor air quality (IAQ) design tools, the object is to advance the state of the art of "traditional" prescriptive standards and design procedures and to enable true performance-based design of IAQ building systems. Older methods of ventilation design use simplistic formulas, requiring a set amount of ventilation per person or per square foot. These methods do not take into account factors such as outdoor pollutant levels and indoor source strengths, and they do not allow the use of innovative design approaches. The most effective and efficient ventilation strategies would be based on the prediction and measurement of contaminant loads, and group staff are working on design tools to facilitate such prediction and measurement. They have completed the calculation engine and are now working on interfaces and applications.

Another project in the Indoor Air Quality and Ventilation Group is the investigation of the impacts of IAQ controls on energy, costs, health, and productivity. By improving understanding in this area, NIST will help building designers make better decisions about which control technologies to use and will help them improve implementation of these technologies. As one part of this project, the group is providing instrumentation support, cost/benefit analysis, and IAQ and energy modeling for a large study of elementary schools. This pilot program is designed to quantify the effects of indoor environmental control on the health and performance of students and staff in elementary schools and to quantify the costs and benefits of these effects. Another part of the project is the recently completed study of IAQ issues at the Oberlin College Environmental Studies Center. Based on this work, NIST staff were able to develop methods for monitoring carbon dioxide in the field and to make recommendations about the role of such monitoring in the commissioning of sustainable buildings.

Finally, the group is conducting a study of testing methods for filtration and air cleaners. This work requires testing and model validation in realistic buildings, ranging from an extensively instrumented single room test house, to a more realistic manufactured house test facility, to an occupied townhouse. This year, the manufactured house test facility was installed at NIST, and the facility will also be used for residential mechanical ventilation testing for reliability, air distribution, energy impacts and controls for different systems, in support of standards by HUD and ASHRAE.

Thermal Machinery Group. The primary focus of the Thermal Machinery Group is on projects to support reduced energy consumption of refrigeration and air conditioning equipment by enabling selection of the best refrigerants and improvements in equipment efficiency. In the first area, the group is providing relevant and unbiased research and information on the performance of carbon dioxide and hydrofluorocarbons (HFCs) as refrigerants, as currently there is a great deal of controversy around the world about the relative energy efficiency of these two refrigerants. The work being done at NIST is certainly state of the art as well as important to the community, as demonstrated in the recent publication that compares carbon dioxide with HFC-134a for automotive air conditioning. The NIST results showed that carbon dioxide systems will have considerably lower energy efficiency compared with that of fluorocarbon systems of a similar design and cost basis. This result is contrary to reports by companies advocating carbon dioxide and has produced much discussion within the industry.

Several other projects in the Thermal Machinery Group also demonstrate the group's effective employment of leading-edge technologies: the use of fluorescence-spectroscopy measurement for determining the concentration of lubricants on pool boiling and convective boiling surfaces, the application of microelectromechanical systems (MEMS) to refrigeration and air conditioning systems, and the development of new computer models for optimizing the design and performance of refrigeration and air conditioning systems. The panel supports these efforts, as they represent technology advances that can reduce energy consumption in building refrigeration and air conditioning systems.

Heat Transfer and Alternative Energy Systems Group. The Heat Transfer and Alternative Energy Systems Group focuses on the sort of metrology programs that are at the heart of BFRL's mission. For example, the goal of the group's thermal conductivity work is to develop the measurement tools, procedures, standards, and databases to assist the building industry and related industries in determining the thermal properties of building materials, industrial insulations, and innovative insulation systems. Thus, staff provide thermal conductivity measurements of insulating and building materials, with traceability to NIST Standard Reference Materials (SRMs) for insulation.

In the area of alternative energy systems, the group develops measurement techniques and validated performance models for building integrated photovoltaic products. Currently, the lack of experimental data and computer simulation tools for determining the performance of building integrated photovoltaics is inhibiting the widespread adoption of this technology. While several predictive models are available in industry, none has been validated with actual data, so the NIST staff have developed and are now operating two systems for data collection. One is a mobile photovoltaic tracking test facility, and the other is a testbed of building integrated photovoltaic panels on the south side of NIST Building 226. Many solar industry companies and academic and governmental laboratories are interested in the data that will be produced and in the results of NIST's use of the data for model validation. In addition to building and using the test systems, the division is also supporting the installation of the first permanent, renewable energy system at NIST, an integrated photovoltaic system in the Administration Building.

Program Relevance and Effectiveness

The Mechanical Systems and Controls Group has long been recognized as an industry leader because of its work on BACnet and on FDD. The group's success is based on a hands-on approach, including real-world demonstrations. For example, a key to the effectiveness of the BACnet program was the hands-on approach to developing virtual testbeds and the use of field demonstrations (e.g., at the Phillip Burton Federal Building in San Francisco) to establish the value of BACnet systems. Currently, the decision to develop and demonstrate an enterprise monitoring system with GSA is a good example of the group's ability to understand how to influence an industry. Working with a large, forward-thinking customer such as GSA will ensure that the findings and successes will be replicated widely within that customer's buildings, as well as by other organizations. The panel recommends that the group continue pursuing new demonstration opportunities.

Demonstrations are not the only way that the Mechanical Systems and Controls Group disseminates its results and encourages the use of new technologies. For example, the group has helped form the BACnet Manufacturers Association, which is an important step in the evolution of the standard from a paper description to its use in real-world products. The association has more than 25 members, only 2 of which (including NIST) are nonmanufacturers. BACnet has the potential to be used on an international scale, and staff have expanded their leadership activities to include work with the European BACnet Interest Group, and an effort to establish a BACnet-like standard through the ISO and individual countries within Asia.

Another way that the group facilitates technology transfer is through informal personal relationships with industry representatives. For example, staff's interactions with controls manufacturers during BACnet development activities gave them the opportunity to inform those manufacturers about the group's FDD work, and as a result, some of the manufacturers have chosen to implement FDD in their controllers. In these sorts of interactions, the panel recommends that the group be careful to work closely with both a manufacturer's marketing and technical representatives; relationships with both departments is the only way to ensure that the interaction will result not just in interesting demonstrations but also in products that are actively marketed by these companies. The use of CRADAs with these companies is highly encouraged.

While the Mechanical Systems and Controls Group certainly provides key results in support of the development of individual technologies, the group's real relevance and vision can be seen in the way that the activities of multiple programs are integrated. For example, the use of the VCBT to develop, test, and demonstrate FDD routines in BACnet-compliant controllers linked with the GEMnet project shows that NIST has a vision for the cybernetic buildings of the future. By developing the pieces—communication and information standards, algorithms, and testing devices—and demonstrating integration in the field, NIST will play an important role in enabling industry to achieve this vision. The key challenge to the group will be communicating developments in these areas and working effectively with industry to see that the vision is realized in commercial products.

Life-cycle information management—the exchange of detailed and accurate building information across the complete life cycle of a facility (including design, construction, and operation)—is a highly relevant objective that the panel believes should be pursued not only in the Computer Integrated Construction Group and Building Environment Division but at the laboratory and institutional levels as well. While visionaries within the buildings industry have been promoting life-cycle information management for several years, the industry as a whole was not embracing the idea, as noted in last year's assessment. However, the events of September 11 changed this situation by demonstrating why ready access to complete and accurate information about a building and its systems is important throughout the building life cycle. Participants at a February 2002 workshop sponsored by the Defense Advanced Research Projects Agency expressed great interest in using the IAI/IFC data model as an information repository to support tools such as CONTAMW which could help with delivering and operating buildings that have improved performance under adverse conditions (such as the release of chemical and biological agents). Now industry support clearly exists for the division's efforts in this area, and end users now may be interested in making use of the group's results.

Computer Integrated Construction Group staff are continuing their long-standing participation in both national and international standards efforts. These activities ensure that the work undertaken within group projects is well informed at the technical level, is both leveraged by and integrated into the work of others, and achieves a high level of visibility in external communities. In the product data standards areas, staff work with both established and nascent organizations and ad hoc groups relevant to the architecture, engineering, construction, and facility management industry. This is a diverse and fragmented industry that spawns numerous standards efforts, and it is critical that NIST remain cognizant of and involved in all of them. If software interoperability is to be advanced, continually evolving standards for building information such as STEP, IAI/IFC, and XML need to be harmonized, or at least gross conflicts inhibiting data exchange must be avoided. NIST is one of the few institutions with the appropriate objectivity, and the Computer Integrated Construction Group has the requisite historical knowledge and organizational connections to help monitor and promote this task in collaboration with its peers in industry organizations and related research communities.

In another example of key standards committee participation, the head of the Indoor Air Quality and Ventilation Group is the current chair of the ASHRAE committee (SSPC 62.1) responsible for the standard for ventilation for acceptable indoor air quality. His work on this committee provides the group with a clear understanding of the drawbacks of current prescriptive standards, the research and tools that are necessary before a best practice can be incorporated in a standard, and the mechanism for working with industry to move toward more innovative standards. The committee is currently at the center of a significant amount of controversy, and it is appropriate that NIST supply unbiased technical leadership in order to allow this activity to move forward.

The relevance of the Indoor Air Quality and Ventilation Group work to BFRL's new focus on homeland security programs has already been demonstrated in the government's response to the anthrax mailings. After the release of anthrax spores at the Hart Senate Office Building, there was interest in understanding how the spores were likely transported throughout the building. Thus NIST was asked to provide assistance in analyzing contaminant transport patterns in this building. Because a model of the building did not already exist and because access to the building was understandably limited, researchers had to make many assumptions in order to create a model of the ventilation systems that could be used with the group's contaminant flow prediction tools. Despite these constraints, the project was successful and demonstrated the importance of being able to perform this type of analysis. As a result, organizations such as the Architect of the Capitol and the State Department are sponsoring an activity to create models of certain critical facilities so that, if necessary, contaminant modeling can be completed more accurately and faster (perhaps even quickly enough to provide information to first responders). Other customers for the group's building modeling activities include DARPA, which is considering including NIST tools in its Naval Surface Warfare Center Immune Building Toolkit, and ASHRAE, which invited division staff to participate in its presidential study group addressing building safety under extraordinary incidents. For security reasons, researchers who worked on the Hart Senate Office Building modeling effort are not at liberty to discuss their findings, and the panel notes that many of BFRL's homeland security activities may be constrained in this way. The laboratory will have to find ways to publicize successful and relevant results while respecting sponsors' need for secrecy.

In the Thermal Machinery Group, programs are established on the basis of industry needs, as determined by close interactions between NIST staff and representatives from industrial, governmental, and academic communities. External institutions collaborate on group projects and provide funding to support work of value to them. For example, the Air Conditioning and Refrigeration Institute has provided funding for the project designed to determine the performance of hydrofluorocarbon refrigerants operating at high ambient temperatures and for the work on the potential use of MEMS to control refrigerant distribution in multiple evaporator circuits. The Department of Energy has supported the project to study heat transfer effect of lubricant layer thickness on heat exchanger surfaces, and the group has several industrial collaborators on this effort.

As a result of good external relations, the Thermal Machinery Group projects have access to key information, and they have significant impacts on relevant communities. The group's programs for modeling refrigeration and air conditioning system performance can be purchased through the NIST Standard Reference Data program and have become the worldwide industry standard. A new program for optimizing the design and performance of evaporators and condensers was developed with industry input, and it has been estimated that the use of this program can result in system energy efficiency improvements of 6 to 7 percent.

The Heat Transfer and Alternative Energy Systems Group also effectively utilizes collaborations and funding from external institutions. Many years of work on thermal conductivity measurements have benefited from input and funding from the Department of Energy, the North America Insulation Manufacturers Association, and private industry. Currently, the photovoltaic measurement work is being partially funded by the California Energy Commission, and it is receiving technology support from Siemens, BP Solar, and Astropower. Additional cooperation and input are being received from the University of Wisconsin Solar Energy Laboratory, the Florida Solar Energy Center, and Sandia National Laboratories. Photovoltaic systems have the potential to provide an alternative source of energy (other than oil), and the growing interest in NIST's work in this area in part reflects concerns about the environmental impact of global warming from the burning of fossil fuels and about the continued conflicts near Middle East oil fields.

The Heat Transfer and Alternative Energy Systems Group does not rely merely on its relationships with collaborators and funders to disseminate group results. In the photovoltaic area, six papers were published by staff in 2001. In the thermal conductivity area, a database containing thermal conductivity values of building materials has been made available on the Web.[10] In addition, the group has begun an international interlaboratory comparison of thermal conductivity data with Canada, France, Japan, and

[10]The NIST Heat Transmission Properties of Insulating and Building Materials database is available online at <http://srdata.nist.gov/insulation/>.

the United Kingdom, each of which has its own measurement apparatus for thermal conductivity data. This intercomparison could lead to internationally recognized thermal conductivity values for insulating materials and thus could reduce a barrier to international standardization and commerce.

The activities in the five groups of the Building Environment Division do a good job of supporting NIST's customers and fulfilling the BFRL mission. The panel notes that a program on standards related to sustainable buildings would also be consistent with the division's and laboratory's missions and would take advantage of the skills that exist in the division. A great deal of interest currently exists in industry with respect to constructing "green" buildings, although there seems to be little agreement on what is meant by "green." A few rating systems do exist, but they tend to focus on particular areas and are occasionally proprietary and not open to public input. Currently, no definitive and public standard exists to define what makes a building environmentally sound, and thus the potential for misrepresentation is great. For such a standard to be formulated and agreed upon, metrics that include significant amounts of information about the building's design, construction, commissioning, and performance would be required. The Building Environment Division is well positioned to apply its technical know-how and its mandate for unbiased standard setting to this important problem within the industry; sustainable buildings and whole-building life-cycle analysis have the potential to be organizing principles to guide the division's design of its future programs.

Division Resources

Funding. Funding sources for the Building Environment Division are shown in Table 7.4. Last year, the panel was concerned about the dependence of the division on external funding and the absence of clear criteria for determining what sort of outside support is desirable and worth pursuing. It was suggested that BFRL should systematically consider the issues related to external funding and should determine a policy to strengthen the laboratory and division programs and perhaps help mitigate future funding crises. The panel was disappointed to see that the groups did not appear to have been given any

TABLE 7.4 Sources of Funding for the Building Environment Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	3.7	4.1	4.1	4.0
STRS, nonbase	0.7	0.8	1.2	1.2
ATP	0.1	0.2	0.3	0.1
OA/NFG/CRADA	2.0	1.6	1.9	2.8
Total	6.5	6.7	7.5	8.1
Full-time permanent staff (total)[a]	36	35	35	37

NOTE: Sources of funding are as described in the note accompanying Table 7.1.
[a]The number of full-time permanent staff is as of January of that fiscal year.

new guidance on the appropriate use of external funding. The panel continues to recommend that laboratory and division management devote some attention to this issue.

In the past year, the most significant development affecting the resource situation throughout BFRL was the World Trade Center attacks and the anthrax mailings and the resulting new laboratory focus on homeland security. In the Building Environment Division, some resources have been reprogrammed to support new or expanded activities related to homeland security, such as the work on contaminant transport patterns in buildings. While NIST can play an important role in governmental efforts to improve homeland security, funding for such work in BFRL is not yet in place, and whether such funding will be stable is still unclear. Wisely, the laboratory has chosen to outsource some of the activities at this time, but if NIST management and Congress make a commitment to sustaining long-term programs in homeland security in BFRL, the division and laboratory would be well advised to develop more in-house resources to support these activities. (The Indoor Air Quality and Ventilation Group, in particular, would have to grow significantly.)

One consequence of the recent reprogramming to support homeland security programs was a cut in the internal funding supporting the Thermal Machinery Group's work on the evaluation of low global warming refrigerants such as carbon dioxide. This project provides the high-quality, unbiased technology evaluations necessary for the refrigeration and air conditioning industry to make good decisions about technologies to increase energy efficiency. The panel is concerned that, with the recent cut in internal funding, the Thermal Machinery Group as a whole now is highly dependent on external funding.

Human Resources. As of January 2002, staffing for the Building Environment Division included 37 full-time permanent positions, of which 33 were for technical professionals. There were also 8 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The division is making effective use of guest researchers, students, and contract labor. The Thermal Machinery Group, in particular, seems to utilize visitors and graduate students well. This leveraging of permanent staff with temporary employees is important, as it allows the division to respond flexibly to fluctuations in total laboratory funding. The panel is also pleased to see that the division is making an effort to hire technicians to run the instruments, allowing researchers to use their time more efficiently.

Morale in the division appears to be relatively high, although the panel did note concerns about frequent reorganizations within the laboratory and a lack of clarity in the prioritization process.

Most of the groups appear to have an adequate number of permanent staff, but in two groups the number of personnel is a little low. The Mechanical Systems and Controls group has recently lost several staff members, but a search for at least one new individual is under way. The panel encourages the group leader to utilize personal networks as well as advertisements to find qualified candidates. The Computer Integrated Construction Group is definitely spread too thin at this time. Current staff do not have enough time to devote their undivided attention to the technical work necessary to meet the identified milestones of each project. While the group is currently interviewing people in a search for a new permanent employee, finding qualified candidates is very difficult in this area.

Instruments. The Thermal Machinery Group is to be commended for acting on the panel recommendation for removal of methylene chloride from the truck environmental chamber cooling system. The group worked cooperatively with the NIST Plant Maintenance Division to obtain adequate funds and has completely revamped the cooling system valves and controls and replaced the methylene chloride with a more benign heat transfer fluid.

In the past year, a number of new facilities have been completed in the Building Environmental

Division. In the Indoor Air Quality and Ventilation Group, a manufactured house test facility was installed to provide unique and important capabilities to support the study of testing methods for filtration and air cleaners. In the Heat Transfer and Alternative Energy Systems Group, a new leading-edge apparatus for high-temperature measurements of thermal conductivity reference materials will soon be completed (funding is in place), and the panel applauds the group for recognizing the need for this test system and for obtaining the support necessary to finish construction of the apparatus. Unfortunately, funds (~$200,000) are not yet available for an associated vacuum system. The Heat Transfer and Alternative Energy Systems Group has also decided that in the future, laboratory facilities for evaluating residential fuel cell system performance will be needed. A proposal for this type of facility has been prepared, and the group is seeking funding from industry and governmental agencies. The panel supports this effort to establish a fuel cell test laboratory.

Fire Research Division

Technical Merit

The mission of the Fire Research Division is to develop, verify, and utilize measurements and predictive methods to quantify the behavior of fire and the means to reduce the impact of fire on people, property, and the environment.

The work in the Fire Research Division is mainly in support of the Building and Fire Research Laboratory's goal of fire loss reduction. This BFRL goal is focused on four key objectives: reducing residential fire deaths, injuries, and property losses; reducing firefighter line-of-service deaths and burn injuries; enabling engineered fire safety for people, products, facilities, and first responders; and reducing firefighter and occupant vulnerability in extreme fire events that threaten homeland security. Currently, these objectives are supported by four technical programs in the Fire Research Division: Advanced Fire Service Technologies, Reduced Risk of Flashover, Advanced Measurement and Predictive Methods, and Homeland Security. The first three programs are continuing efforts. The panel was presented with information about the goals and objectives of the first three programs and was pleased to note that these goals and objectives were much more clearly defined and specified than last year. The metrics for what the division wishes to accomplish (such as helping to achieve a 25 percent reduction in line-of-duty fatalities and burn injuries in the United States by 2007) have become more quantifiable. However, the panel notes that many of the goals are still listed on the time scale of many years, so it is difficult to use them to measure the progress of the division's ongoing activities from year to year.

The division was formed in 2000 through the merger of two divisions. The panel was very pleased to see how effectively the merger has progressed. The division is currently organized in five groups—Fire Fighting Technology, Fire Metrology, Analysis and Prediction, Integrated Performance Assessment, and Materials and Products—and the reorganization has allowed these groups to work together rather than competitively and to share a common focus. An environment of synergy exists between the five groups; scientific relationships between groups are very good, and personnel interact almost seamlessly across group lines. The panel noted that collaboration and communication with other divisions has also increased. More could still be happening, and the Homeland Security Program will offer a good opportunity for the Fire Research Division and the Structural Division to develop a productive working relationship on joint projects.

While it believes that the merger has been successful, the panel does have one concern about the current organizational structure. The approach of having five groups (corresponding to the division's core areas) and four technical programs (that support the laboratory's fire loss reduction goal) is causing confusion. Group leaders appear to have all the authority, while program leaders have the technical mandates. For instance, a deliverable in a given program is not reviewed by the investigator's program manager, but rather by his or her group leader. Performance reviews are similarly the domain of the group leaders. Thus, program managers have little ability to control and direct the work for which they are responsible.

In general, the division devotes serious attention to project and program planning. While this is an important activity, it can also be time-consuming and has the potential to distract staff from their technical responsibilities. The focus on planning is understandable, as the division is completing the merger and the new focus on homeland security is being defined; however, care needs to be taken going forward to include staff in planning without extensive disruption of their technical work.

In the review of the Fire Research Division's activities, the panel saw a number of impressive projects. One example is the work on high-throughput flame retardancy measures. The division staff have developed a system in which polymers are extruded to produce a long sample that has a continuous gradient in composition. Samples can then be exposed to a horizontal ignition and flammability test. This approach allows researchers to determine the flame speed continuously as a function of composition and flux level. This new high-throughput experimentation technique will support more efficient work on the discovery and characterization of new fire-resistant materials.

Another example is the work on experimental characterization of flame spread and fire growth rate. Data will be collected in tests containing materials and geometries representative of real-world situations. The ultimate goal is information to support the development of an engineering model and to increase the understanding of the fire growth and spread leading up to the point of transition to flashover. Such a model would be useful for understanding how the flammability characteristics of furnishings and contents could be improved and for providing a basis for the design and development of detection and suppression technologies.

A third example of a noteworthy project is the work on early, fault-free detection of smoke and fires. A key component of this program is the development of a fire-emulator/detector-evaluator. This system has been designed to measure the performance of fire detection systems in a variety of situations (including not only the system's ability to detect smoke from a real fire, but also the system's reaction to nuisance sources such as cigarette smoke, steam, and the cooking of foods). A quantifiable, repeatable test of how well a particular design can discriminate a flaming or smoldering fire from a nonfire event should enable the development of effective new systems, which, it is hoped, will lead to an overall reduction in false alarm rates.

The final example of particularly impressive division products is the Fire Dynamics Simulator (FDS), the result of a continuing, long-term effort by BFRL. The FDS uses zone and field approaches to model fires, and division staff are continually developing new algorithms and modeling approaches and improving the capabilities of this important NIST product. The FDS is an excellent scientific and engineering tool, and the panel believes that the division and laboratory should consider building a major programmatic thrust around the FDS. Work would focus on Large Fire Research Facility experiments aligned with FDS's predictive capabilities and on continuing to improve the components of the model.

Homeland Security. An important new development in the division this year is the emerging program in Homeland Security. In this program, the division will apply measurement and predictive methods to identify the role of fire in the World Trade Center collapse, to improve methods of structural fire protection and emergency response, and to reduce firefighter and occupant vulnerability. The division has already begun the work on the first part of this program. Here, the staff are using the FDS to model the fires in the World Trade Center on September 11. This work is an ongoing effort, but already comparisons between the modeling results and data from the event have allowed staff to deduce information about critical factors in the fire, such as the amount of airplane fuel expended in the fire ball at the time of collision and the importance of the internal geometry of the building and wind effects in the progression of the fire. This analysis is a significant investigative approach, and the panel does not believe that it is being done anywhere else. The division's ability to estimate important parameters and to make these deductions about the fire is based on years of work at BFRL on constructing and validating NIST's critical fire modeling capabilities. For example, the submodels used as inputs to the FDS are a major strength of the simulations, as these submodels can predict the smoke produced and therefore computationally predict the plume formed.

The division's work on modeling the fires in the World Trade Center is one piece of the BFRL-wide study of the collapse. The Fire Research Division will have a significant role in this FEMA-requested investigation, as well as in the laboratory's more general work in the area of homeland security. For example, the division's expertise will be essential in projects on determining the impact of temperature and heat on structural failure and assessing and predicting fire and explosion damage, and NIST's work will support the design community's efforts to design more blast-resistant structures. The homeland security program is a great opportunity for BFRL to make a difference in an important area, and the panel encourages the division and laboratory to actively pursue this work. However, to be successful, the mission of the NIST program needs to be clearly articulated, and strong interactions between the Fire Research and Structures Divisions are essential.

The division's and laboratory's homeland security plans appear to be very ambitious, and a great deal of work will need to be done. The panel recognizes that the division may not be in a position to do all of the work in-house but does believe that it is important to maintain at NIST the expertise necessary to fulfill a leadership role, that is, to oversee and act as advisers to related projects outside NIST, and perhaps even to guide the work done elsewhere. For example, the panel believes that the federal government should have access to a simulation tool that couples a fluid dynamics model (to simulate blasts and subsequent fires) and a structural dynamics model (to describe the effects of blasts on buildings and possible subsequent collapses). While such coupled models do exist already and are probably being adapted to study problems related to homeland security, the panel believes that the expertise and tools should also be available at NIST. This is one example of an area in which close collaboration between the Fire Research and Structures Divisions would be necessary. Contacting groups at other institutions, particularly the Department of Defense, may also be a way to access models that division staff can combine and adapt to build this capability.

Program Relevance and Effectiveness

The Fire Research Division has a good vision of how its objectives match up with the needs of its stakeholders and of how its results will be used by these stakeholders. Division products can be directly implemented in many cases to reduce direct and indirect fire-related costs, improve life safety in fire situations, improve U.S. economic competitiveness internationally, and facilitate regulatory improvements and reform. Programs under way that will have such an impact include those in protective clothing research, research on smart zone fire alarm systems that incorporate informational displays for firefighters responding to fires in large buildings, simulations to improve understanding of various fire situations (including college dormitory fires and fire spread in urban wildlands), techniques for predicting structural collapse due to fire, study of the effects of positive pressure ventilation and various types of hose streams, and experimental and modeling projects relevant to defining fire codes and standards.

In addition, a number of projects are focused on pragmatic approaches to enhancing residential fire safety, such as assessing hazard reduction for bed fires, and mattress screening tests. While these efforts are modest individually, collectively they represent significant opportunities to reduce the number of lives lost in fires.

The Fire Research Division's objective of improving firefighter safety is appropriate and commendable. Currently, a primary focus of the division's efforts is on reducing the risk of flashover. This is an important area, and the division can make a difference here. However, the panel suggests that the division consider expanding its approach to areas beyond flashover and determine what factors other than flashover contribute to fire-related fatalities, injuries, and property loss. A more comprehensive understanding of the various factors will help the division determine the most effective ways to impact the economics of the public and personal costs of fire.

The division continues to expand efforts to disseminate NIST products and findings to an array of diverse customers. Examples of recent outreach efforts include the organization and hosting of the 12th International Conference on Automatic Fire Detection in March 2001, the distribution of more than 6,000 copies of the flashover video and 8,000 compact disks of the Cherry Road simulation for use in firefighter training and public safety awareness programs, the public release of Version 2 of the FDS in December 2001 (FDS is available on the Web[11] and has been downloaded more than 1,000 times), and impressive and productive interactions with the U.S. Fire Administration.

The Fire Research Division is well respected by members of its stakeholder communities nationally and internationally. However, the panel notes that a systematic approach to communicating with stakeholders and the public is not in place in the division or in BFRL as a whole. Perhaps a strategy should be developed at the division or laboratory level to facilitate the transfer of information produced at BFRL to the laboratory's customer base. Possible approaches might include the development of a central laboratory communications office or other methods to allow utilization of appropriate links to the media. Currently, the general public is not aware of the value of the division's work. The panel applauds the recent smoke alarm demonstration staged for the media in the Large Fire Research Facility as a step in the right direction. The organization of additional workshops with representatives from industry, government, and academia, firefighters, and other relevant groups would also help publicize the benefits produced by the work of the Fire Research Division. The ultimate goal is timely communication to the stakeholders of BFRL.

Division Resources

Funding sources for the Fire Research Division are shown in Table 7.5. The balance between internal and external funding has improved. In FY 2000, the last year in which two separate fire divisions existed, outside funds accounted for 41 percent of the divisions' budgets. In FY 2002, external money is estimated to be 35 percent of the funding for the unified division. This decreased percentage reflects an increased congressional allocation (STRS). The panel supports this trend, as it allows the division to maintain a reasonable balance between time spent conducting research and time spent seeking outside funding.

A key issue for the Fire Research Division going forward is its role in BFRL's (and NIST's) new strategic focus on homeland security. The division is already making important contributions in this

[11]The Fire Dynamics Simulator is available online at <http://fire.nist.gov/fds/>.

TABLE 7.5 Sources of Funding for the Fire Research Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999[a] (actual)	Fiscal Year 2000[a] (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.2	4.7	5.9	7.3
Competence	0.2	0.0	0.0	0.0
STRS, nonbase	0.6	0.5	0.5	0.5
ATP	0.1	0.2	0.5	0.3
OA/NFG/CRADA	3.6	3.9	4.0	4.3
Other Reimbursable	0.0	0.1	0.0	0.0
Total	9.7	9.4	10.9	12.4
Full-time permanent staff (total)[b]	56	57	52	52

NOTE: Sources of funding are as described in the note accompanying Table 7.1.

[a]The funding and staff totals for fiscal year 1999 and fiscal year 2000 are the sums of the numbers from the Fire Safety Engineering Division and the Fire Science Division, which were combined at the end of fiscal year 2000 to form the new Fire Research Division.

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

area, as discussed above, and the time and effort that the division devotes to this area are expected to expand. The division staff are entirely supportive of this programmatic emphasis and are eager to help in the defense and protection of the nation. However, the impact of the homeland security work on the rest of the division's projects is unclear, and the uncertainties associated with this change in direction are affecting morale. The morale of the entire laboratory was also hurt by the delays in determining the role of NIST in the governmentwide investigation of the events of September 11. While BFRL staff began to apply their expertise immediately where they could, such as in modeling of the fires in the World Trade Center, the lack of clarity within the federal government about what NIST would do and about whether funds would be provided for their efforts has been unsettling for all BFRL staff.

The Large Fire Research Facility will be a key component of the homeland security effort. After several years of renovation, this extremely impressive facility is now essentially complete, and it will be used to support ongoing research in the division as well as to meet the fire testing needs of BFRL's customers in industry, government, and academia. The panel is somewhat concerned that development and utilization of the refurbished facility are proceeding slowly. It seems that each individual item of instrumentation has to be implemented at the highest level before staff move on to installing the next instrument. While excellence is an appropriate goal, the panel believes that this very measured pace of installation has interfered with the active and productive use of the facility. Given the cost of the improvements, ensuring that the facility is used and that full advantage is taken of the relatively rare large-scale testing options that it provides should be a priority. Improvements in measurement capabilities should be viewed as an ongoing and evolutionary process.

The panel is pleased to see the Large Fire Research Facility operational, and it believes that the laboratory should immediately begin planning for future improvements. How, and how often, the facility is used for measurements that utilize its unique capabilities should be tracked so that the need and case for future expansion can be documented. The division should focus on determining what improvements are required to make this a world-class facility and on facilitating its use in support of NIST's homeland security work.

As of January 2002, staffing for the Fire Research Division included 52 full-time permanent positions, of which 46 were for technical professionals. There were also 13 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

One senior scientist retired from the Fire Research Division this past year. Over the next few years, several more retirements are expected. The panel is concerned that the division's planning for this transition is insufficient. Major gaps in expertise will result from these retirements, and recruitment of new staff to fill these holes will be needed.

Codes and Standards

In the aftermath of the events of September 11, 2001, the world is looking to the United States to develop and explain ways of bringing an acceptable safety and comfort level to the design and construction of the built environment. This is the time for BFRL to make an impact on the building codes and construction standards used in the United States and around the world. In the past, BFRL has been slow in formulating an approach to codes and standards efforts, but now the laboratory must continue its work on developing the metrics and techniques that will support the use of modern and effective codes and standards and must move quickly and surely to ensure the adoption of such codes and standards by national and international regulators.

A wide range of questions has been raised in response to the fires and collapses at the World Trade Center. BFRL is well positioned to draw on past results and existing expertise to contribute to work in relevant areas. Unfortunately, in the aftermath of the destruction in New York City, legitimate proposals for new approaches are mixed in with flawed plans proposed and widely advocated by opportunists and misguided individuals. Laboratory staff will have to both provide support for sound ideas and work to negate proposed standards that would be ineffective, inappropriate, or even dangerous.

In the Structures and the Fire Research Divisions, staff are qualified to contribute to the debates on many questions related to the structural and fire safety of tall buildings. Areas that BFRL will be expected to study include these:

- The protection of structural frameworks from the effects of fire. A particular focus will be the level of protection provided by sprayed-on fireproofing systems.
- The protection of the structural framework from the effects of impact loading. This topic is an example of one in which NIST's focus should be on the dissemination of past results, which affirm that the issues are well understood and that additional study is not needed.
- The adequacy of the in-place fire protection systems (to protect human occupants and structural frameworks). Again, dissemination of past results in this area is all that is needed.
- The protection of structural systems from impacts such as from large airplanes. In this area, proactive work by NIST is necessary to explain how the structural engineering formulas that are currently in place are adequate to resist the effects of fire and other hazards such as wind, earthquake, and flood. The focus on airplane impacts, while understandable, has the potential to distract the community from considering more important questions.

Other critical questions facing the building design community at this time relate to building access and egress. For example, some comments have been made about whether the exiting system of the World Trade Center was adequate to handle a full evacuation of the building. It is likely that past work done at NIST and elsewhere will confirm that the system was sufficient, but the design of systems to allow efficient and safe egress from buildings and facilities is an important component of building design, and the best methods must be affirmed and explained. One element of any discussions about exiting systems will be the role of elevators and other mechanical conveyance systems as means of egress in emergency situations. In the past, legal issues have prevented elevator manufacturers from supporting the use of their products in those situations, but the time appears to be right to revisit this issue. NIST has completed many studies in this area and now can provide key information for educating the public about the safe use of elevators and other mechanical systems in emergency evacuations.

BFRL can also play a critical role in support of homeland security by facilitating first responders' access to better information and tools. The best ways to gain access to buildings and facilities during emergency situations are still poorly understood. Also, improvements could be made in communication and warning systems to ensure that the first responders have the information they need and are not unnecessarily placed in risky environments.

The audience for BFRL's work in all of these areas includes the manufacturers of relevant products and regulators in the United States and in other countries. However, for BFRL's work to influence codes and standards, staff must take into account regulators' need for timely information. Regulators will be open to efforts that scrutinize existing codes and work to bring them up to date, but they will not be receptive to lengthy, time-consuming projects. The building codes that are currently adopted and enforced in the United States are updated yearly but are formally reprinted on a 3-year cycle. The changes that will be incorporated in the 2003 publication of the codes are currently undergoing approval now. Thus, BFRL must focus on producing results that can be used to make changes in the codes that appear in the 2006 edition. For regulators to accept and adopt the laboratory's results, work at NIST must be completed before the end of 2005. This schedule is ambitious, but it can be met, as BFRL has already produced important work in relevant areas that it can build on in its new projects.

The biggest potential barrier to BFRL's completing the work needed to impact codes and standards in the United States and abroad is a shortage of resources, particularly human resources, that NIST can devote to this task. In early 2001, the leader (and sole staff member) of BFRL's small existing program in codes and standards retired. While laboratory management has agreed that half of the time of a senior researcher in the Fire Research Division may be allocated to work in this area, the panel believes that this is insufficient. In addition to this person, who brings appropriate technical capabilities and experience with national and international codes and on standards committees, people are also needed who are familiar with the workings of the codes and standards agencies and who can monitor regulatory processes in a number of fields to ensure that BFRL is up to date on relevant deadlines and opportunities. New funding is expected from FEMA that could be used to support the assignment or hiring of additional staff. Much work will still need to be outsourced to other laboratories and agencies, but BFRL must be in a position to track and coordinate all of these activities.

Coordination of the technical work occurring within BFRL is also essential. While participation on codes and standards committees is important, and while the current leader of the laboratory's efforts should continue with his work on these committees, committee work is not the only activity required to support a comprehensive strategy to influence the codes and standards adopted by regulators and used by the design and construction industries. Staff throughout BFRL should take codes and standards needs into account in planning their projects, and BFRL management should support efforts to integrate technical results into national and international codes and standards processes.

Office of Applied Economics

Technical Merit

The mission of the Office of Applied Economics (OAE) is to provide economic products and services through research and consulting to industry and government agencies in support of productivity enhancement, economic growth, and international competitiveness, with a focus on improving the life-cycle quality and economy of constructed facilities. This mission is accomplished exceedingly well by OAE. Staff employ state-of-the-art methodologies to perform first-class analyses of the economic impact of various technologies, and the office's success is due not only to the quality of the evaluations it produces but also to the staff's recognition of the importance of getting results into the hands of the ultimate users by transforming OAE methodologies into useful tools for practitioners. The panel's judgment that OAE's work is of high technical merit reflects the personnel's credentials and the quality of their published reports, and it also hinges on their communications skills, primarily their ability to design effective, interactive, user-friendly computer tools.

OAE is not focused on theoretical economics or operations research. Conceptual advances made by OAE staff are made in the context of solving problems, analyzing data, performing simulations, and gaining insights into the human response to and interaction with evolving technologies. OAE staff are superb at sorting through and applying the very latest theoretical insights in a practical way to behavioral problems associated with technological advances pioneered at NIST. Because OAE always focuses on the ultimate users and on how they will distill and incorporate new information into their decision-making processes, the products delivered by OAE are widely and effectively used by their customers.

Life-cycle costing—one example of an area in which OAE has produced important tools—has been elevated to a usable art because of formats and methodologies developed at OAE, and both the Department of Energy and the Department of Housing and Urban Development have contracted with OAE to provide tools for their constituents. The user-friendly interactive design tools include the Bridge-LCC computer program,[12] which allows the designer to explore the cost-effectiveness of employing new materials. Another area in which OAE excels is in the development of analytic tools to facilitate wise choice among criteria, including criteria that are not easily quantifiable. In one example, the Building for Environmental and Economic Sustainability (BEES) program allows designers to evaluate trade-offs between economic and environmental consequences of building material choices. In another example, an analytic hierarchy method is applied to the evaluation of strategic choices, including project choices within NIST. This technique has also been incorporated into recent work on developing industry-specific indicators to evaluate the likelihood that particular new technologies will be adopted. If this approach is successful, BFRL and NIST might be able to better predict the potential impact of their work and thus make better decisions about whether to fund research and development efforts in a given area or on a particular technology.

As NIST's only substantial group of social scientists with expertise in economics and decision making, OAE staff are regularly relied upon to explore potential effects of human interaction with technical innovations in terms of the overall likely consequences on the desired outcome. For example, one of the staff's more-complicated tasks might be evaluating the trade-offs in emergency situations such as fires, where an improvement in the physical security of exit pathways could reduce the rapidity of human exit, thereby increasing the chances of catastrophic injury.

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[12]LCC, life-cycle costs. Bridge-LCC is available online at <http://www.bfrl.nist.gov/bridgelcc/welcome.html>.

In support of the new focus of NIST and BFRL on homeland security activities, OAE's technical competence in modeling behavioral response can be an essential component of activities assessing risk management strategies for response to possible terrorist threats. Many possible methods exist for improving the security of citizens, and these methods go well beyond developing, designing, constructing, and maintaining more secure, resilient facilities. Cost-effective human security results from the complex interactions between human behavior, both in perpetrating threatening activity and in responding to it, and the physical, transportation, life-support, and IT/communications infrastructure. There are four ways of reducing the undesirable consequences of an assault, whether the cause of the assault is natural or human: avoid it, withstand it, escape from it, and recover from it. Enhanced ability to predict the onset of an assault can improve people's ability to perform effectively in all of these areas, and understanding the likelihood of being able to make such predictions should be taken into account in all BFRL activities on homeland security. OAE staff can help estimate predictive possibilities and can also provide assessments of how human behavior will impact the effectiveness of technologies for reducing the impact of terrorist events. Systematic inclusion of OAE perspectives, methods, and analyses in BFRL work on counterterrorism will enhance the likelihood that the laboratory will make cost-effective, competent contributions to the homeland security effort.

In the past, the codes and standards activities have been organizationally affiliated with OAE in the laboratory office. Due to the retirement of the leader of those activities, the responsibility for the BFRL codes and standards work has been shifted to staff in the Fire Research Division. One of the goals of this work is that of moving codes toward using performance-based measures for building and construction standards rather than merely listing specifications about particular materials; thus, OAE expertise on likely human responses to new standards will continue to contribute to the laboratory's work in this area.

Program Relevance and Effectiveness

Since an appreciable part of OAE's work is customer assessment for other NIST activities, office personnel are certainly well aware of who their own customers are. OAE monitors the hits on its Web site and found that for the 8-month period between March and the end of October 2001, there were 182,496 visits to the OAE directory and another 8,366 to the information on life-cycle-costs for bridges (developed in conjunction with the Building Materials Division). More than 50,000 of those Web inquiries were for full reports, with the UNIFORMAT II system of cost assembly, the ERATES Manual, and BEES receiving the largest number of hits. Furthermore, the widely used RS Means series of publications on cost estimation now includes in its publicity the boast that these publications use the OAE-developed UNIFORMAT II and that it is "easy to use" and the "industry standard." This is a good indication of how OAE is successful at influencing industry behavior.

The Office of Applied Economics provides a wide variety of services and products for BFRL, other NIST laboratories, and many NIST customers. OAE regularly estimates the value to society of alternative technologies; this work benefits NIST by demonstrating the worth of its products, and it benefits customers by helping them choose and implement innovative new approaches. BFRL and NIST also are well served by OAE's assistance in internal project selection and budgetary procedures.

Office Resources

Estimated FY 2002 funding for the OAE totals $1.9 million, of which 62 percent is from external sources. As of January 2002, staffing included 11 full-time permanent positions, of which 9 were for technical professionals.

OAE staff have a diverse blend of complementary knowledge and skills, from economics, to operations-research-based analytic decision-making tools, to statistical and computer-science methodologies. Morale is high, and staff seem to get along well together. Collaborations within the office occur easily. However, the current number of staff is not sufficient to support the wide range of activities at NIST that might benefit from OAE's help. This shortage is particularly emphasized by NIST's expanding responsibilities in homeland security, where understanding human behavior will be an essential part of forging effective outcomes. OAE would certainly be better positioned to undertake the required comprehensive analyses if it could add two or more senior economists or applied operations-research specialists in each of the next several years.

However, finding and hiring staff with the right skills to complement existing OAE personnel would not be easy. Most new economics Ph.D.'s from first-rate universities are immersed in arcane equilibrium theory, driven by available mathematical tools, and do not have the background for understanding the dynamics of short-term human responses to technological innovation. Thus, OAE would have to search a variety of interdisciplinary graduate programs (those that provide training in engineering, management, applied economics, and business) and would have to look for candidates with practical work experience at other national laboratories, at research institutes, or in business (former centers for emerging high-tech companies might be good places to look). Individuals with consulting experience and those knowledgeable about working with agent-based models might also be positive additions to the OAE staff.

OAE is very successful at attracting external funding. While this outside support provides verification that the products of the office are of value to its customers, it also seems to indicate to laboratory management that internal funds for this office are not necessary. The panel notes that to support the expansion in personnel suggested above, reliable internal support will be needed.

8

Information Technology Laboratory

PANEL MEMBERS

Tony Scott, General Motors Corporation, *Chair*
Albert M. Erisman, Institute for Business, Technology, and Ethics, *Vice Chair*
Michael Angelo, Compaq Computer Corporation
Bishnu S. Atal, AT&T Laboratories-Research
Matt Bishop, University of California, Davis
Linda Branagan, Secondlook Consulting
Jack Brassil, Hewlett-Packard Laboratories
Aninda DasGupta, Philips Consumer Electronics
Susan T. Dumais, Microsoft Research
John R. Gilbert, Xerox Palo Alto Research Center
Roscoe C. Giles, Boston University
Sallie Keller-McNulty, Los Alamos National Laboratory
Stephen T. Kent, BBN Technologies
Jon R. Kettenring, Telcordia Technologies
Lawrence O'Gorman, Avaya Labs
David R. Oran, Cisco Systems
Craig Partridge, BBN Technologies
Debra J. Richardson, University of California, Irvine
William Smith, Sun Microsystems
Don X. Sun, Bell Laboratories/Lucent Technologies
Daniel A. Updegrove, University of Texas, Austin
Stephen A. Vavasis, Cornell University
Paul H. von Autenried, Bristol-Myers Squibb
Mary Ellen Zurko, IBM Software Group

Submitted for the panel by its Chair, Tony Scott, and its Vice Chair, Albert M. Erisman, this assessment of the fiscal year 2002 activities of the Information Technology Laboratory is based on a site visit by the panel on February 26-27, 2002, in Gaithersburg, Md., 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 2001,* NISTIR 6815, National Institute of Standards and Technology, Gaithersburg, Md., November 2001; 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., February 2002; U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Information Technology Laboratory Publications 2001*, National Institute of Standards and Technology, Gaithersburg, Md., February 2002.

LABORATORY-LEVEL REVIEW

Technical Merit

The mission of the Information Technology Laboratory (ITL) is to strengthen the U.S. economy and improve the quality of life by working with industry to develop and apply technology, measurements, and standards. This mission is very broad, and the programs not only encompass technical and standards-related activities but also provide internal consulting services in mathematical and statistical techniques and computing support throughout NIST.[2] To carry out this mission, the laboratory is organized in eight divisions (see Figure 8.1): Mathematical and Computational Sciences, Advanced Networking Technologies, Computer Security, Information Access, Convergent Information Systems, Information Services and Computing, Software Diagnostics and Conformance Testing, and Statistical Engineering. The activities of these units are commented on at length in the divisional reviews in this chapter. Below, some highlights and overarching issues are discussed.

The technical merit of the work in ITL remains strong. As part of its on-site 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. While it is not possible to review every project in the greatest detail, the panel has been consistently impressed with the technical quality of the work undertaken. The panel also particularly applauds ITL staff's willingness to take on difficult technical challenges while demonstrating an appropriate awareness of the context in which NIST results will be used and the importance of providing data and products that are not just correct and useful but also timely. Many examples of programs with especially strong technical merit are highlighted in the divisional reviews.

The panel is very pleased to see the progress that has occurred in strategic planning in ITL. A significant development over the past year has been the emergence and acceptance of a framework under which the laboratory activities operate. The framework includes the ITL Research Blueprint and the ITL Program/Project Selection Process and Criteria. The panel observed that these descriptions and tools appear to be well institutionalized within each of the divisions and seem to be having a positive initial impact on improving the direction and efficacy of laboratory projects and programs. These frameworks were widely used in the presentations made to the panel, and the panel noted the emergence of a common "vocabulary" with respect to planning and strategy. Increased collaborations between divisions were also observed. 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.

Program Relevance and Effectiveness

ITL has a very broad range of customers, from industry and government and from within NIST, and the panel found that the laboratory serves all of these groups with distinction. In addition to the panel's expert opinion, many quantitative measures confirm the relevance and effectiveness of ITL's programs. One is the level of interaction between laboratory staff and their customers, which continues to rise. Attendance is up at ITL-led and -sponsored seminars, workshops, and meetings; 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.

[2]In February 2002, NIST management announced that the computing services functions currently housed in ITL will be moved into a separate unit, headed by a chief information officer (CIO) who will report directly to the NIST director. This transition is discussed in the "Program Relevance and Effectiveness" subsection, below.

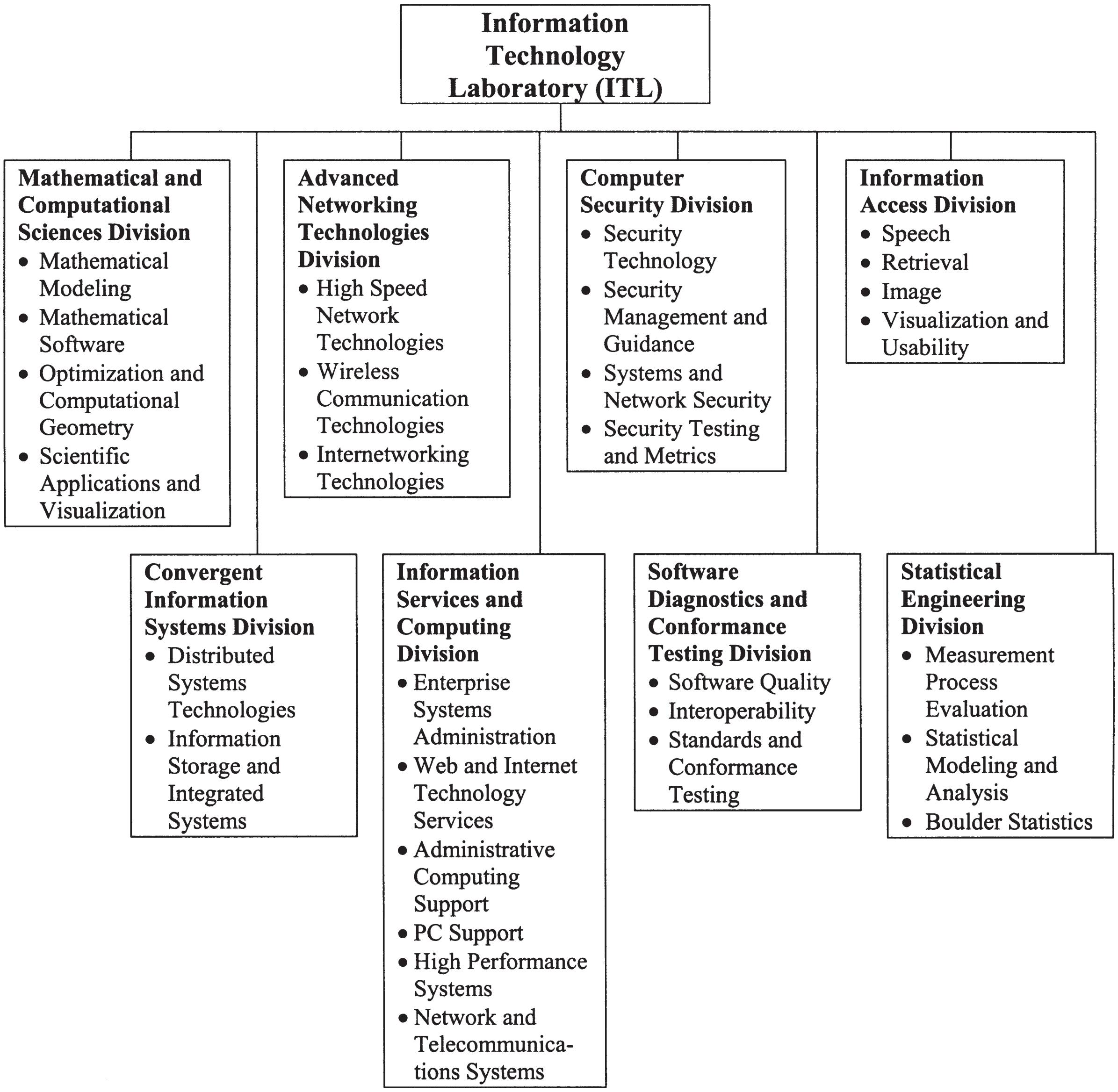


FIGURE 8.1 Organizational structure of the Information Technology Laboratory. Listed under each division are the division's groups.

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 include a Department of Commerce Gold Medal and an RSA Public Policy Award for the work on the Advanced Encryption Standard, an R&D 100 Award for the development of the Braille Reader, a series of awards from the National Committee for Information Technology Standards for leadership in standards-related activities such as the work on standards for geographic information systems, and the election of a staff member as a fellow of the American Society for Quality because of his work on applying statistics to measurement sciences. 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 improve each year, 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, government, and, to some extent, the public). The divisional reviews later in this chapter contain many examples of how ITL makes a difference. Notable cases include the Advanced Networking Technologies Division's success at raising the visibility of co-interference problems between IEEE 802.11 and Bluetooth wireless networks and NIST's technical contributions to evaluating possible solutions; the Convergent Information Systems Division's development of an application that can preview how compressed video appears on different displays, thus allowing producers to make decisions about the amount of compression in light of the equipment likely to be used by the target audience; and the Software Diagnostics and Conformance Testing Division's facilitation of the development of an open standard and needed conformance tests for extensible markup language (XML). In addition to serving all of these customers, ITL projects also have been known to have an impact worldwide. For example, standards developed with NIST's help and leadership in the security, multimedia, and biometrics areas are all used throughout the relevant international technical communities.

In last year's assessment report,[3] 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 significant impact in many areas and should not be squandered by association with organizations that unreasonably restrict membership. The panel continues to urge ITL to establish a 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 inclusionary, 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 these consortia, the panel supports the efforts recently made by ITL and NIST to work on the internal legal roadblocks to participation, but it suggests that this work could be supplemented by efforts to educate external groups, such as consortia members and lawyers, on ways to facilitate NIST's timely participation and technical input. This is a customer outreach effort as well as a legal issue.

One customer that relies significantly on ITL's products and expertise is the federal government, which often uses NIST standards and evaluation tools to guide its purchase and use of information technology (IT) products, particularly in the computer security area. An example is the Computer Security Division's Cryptographic Module Validation Program (CMVP), which has enabled purchasers,

[3] 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.

including the U.S. government, to be sure that the security attributes of the products that they buy are as advertised and appropriate. In the Information Access Division, the new Common Industry Format (CIF) standard provides a foundation for exchanging information on the relative usability of products and is already being used for procurement decisions by several large enterprises. Another key ITL activity relevant to the federal government is the work on fingerprint and face recognition. NIST standards and data have played a key role in the development of automated fingerprint identification systems. Also, since the attacks of September 11, 2001, there has been significant pressure to increase the reliability of biometric recognition technologies, especially face recognition. ITL's existing, long-term programs and expertise in face, fingerprint, and gait biometrics will provide test data that will help drive system development and help government evaluation of systems capabilities.

Programs such as the work on biometrics, especially face recognition, highlight a question relevant to many information technology activities: that is, 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.[4] The panel acknowledges that ITL's primary focus is on technical questions and technical quality, but it emphasizes that for the laboratory's work to be responsible and for the results to be taken seriously in the relevant communities, recognition of the context in which new technologies will be applied is very important. This context has two elements: the deployment of the technology and the social implications of the technology. In the first area, 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 it 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, collaboration across geography, and so on.

Understanding the ultimate goals for new technologies relates to the social implications questions. For example, 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 as security systems in public places—ITL staff made long and arduous efforts to comply with existing privacy legislation. However, when describing the NIST results to public groups (such as the panel), staff should also be sure to take the time to acknowledge the privacy questions and describe potential future issues, as well as discussing the capabilities and benefits of the technological advancements.

Following are two examples of areas in which the panel believes that the potential societal issues or the actual context in which technologies would be used were not being fully considered. The first example is the suggestion that a commercial application for face recognition could be that of having an automated teller machine (ATM) recognize a user with Hispanic features and automatically switch to using Spanish. As many people of Hispanic (or Swedish or Asian) appearance are not in fact speakers of the "native" language implied by their looks, this is a naïve (and perhaps inappropriate) example of the technology's potential. The second example is in the area of pervasive computing, where NIST's work on "smart" meeting facilities was demonstrated for the panel. Recording meetings for search and archiving can offer significant benefits in some contexts, but it can also inhibit certain types of discussions. For example, the effectiveness of brainstorming sessions or examinations of "what if" scenarios

[4]How the social context can provide a framework for information technology development is discussed at length in the following report: Computer Science and Telecommunications Board, National Research Council, *Making IT Better: Expanding Information Technology Research to Meet Society's Needs,* National Academy Press, Washington, D.C., 2000.

might be significantly limited if the participants thought the discussion might later be taken out of context and broadcast.

In addition to strong relationships with customers in industry and in the federal government, ITL places significant emphasis on effectively serving its customers within NIST. The panel commends the focus in both the Mathematical and Computational Sciences Division and the Statistical Engineering Division on building robust collaborations with scientists and engineers throughout ITL and the other NIST laboratories. One example is the work of the Mathematical and Computational Sciences Division on the mathematical modeling of solidification with staff from the Materials Science and Engineering Laboratory; another is the Statistical Engineering Division's development of a method to combine data from diverse building materials studies for the Building and Fire Research Laboratory.

A primary current responsibility of ITL is that of IT support for all of NIST. The relevant activities—which include the support and maintenance of campus networking, personal computers (PCs), administrative applications (such as accounting software), and telephones—are performed by the Information Services and Computing Division. These service programs were unified in this division in December 2000, and the panel is very pleased at the significant progress observed in the past 2 years. The quality and effectiveness of the support functions have improved and so has the overall planning and strategic approach to providing the relevant services. A "NIST IT Architecture" has been developed, and it should help provide context and scope for each of the subarchitectures and various support functions at NIST. Other recent accomplishments include the formation and centralization of a NIST-wide help desk and increased standardization around core processes such as PC procurement. Issues do still exist, however, including a lack of ability for this division's staff to enforce or even check compliance with centralized IT standards or policies. For example, many units at NIST do their own systems administration, which could result in uneven implementation of appropriate security applications.

The key issue for IT services at NIST in the next year will be an organizational transition. In February 2002, NIST management announced that the support functions currently housed in ITL will be moved out of the laboratory into a separate unit, headed by a chief information officer (CIO) who will report directly to the NIST director. Since a significant problem for the current unit is the difficulty in getting the NIST laboratories to embrace consistent, institutionwide standards for IT systems, raising the services unit to a level equivalent with the laboratories may provide needed visibility for the issue. Another factor that may help is the emphasis by the current director of this new unit (the acting CIO) on demonstrating to the other NIST laboratories how IT services can facilitate their research and how standardizing basic applications can save time and money. Achieving acceptance of this new unit and centralized IT support across NIST will be a serious leadership challenge, as this approach will be a cultural shift for NIST. The panel encourages benchmarking with organizations such as Agilent Technologies that have successfully made such a transition.

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 effectively used throughout NIST. Applying the development work of ITL's research divisions to NIST as a whole will require the continued tracking in the services unit of relevant ongoing projects and the recognition in ITL of the potential for using NIST as a whole as a testbed.

ITL has done a remarkable job of becoming more customer-oriented over the past several years. The panel applauds the laboratory's efforts in outreach and notes that the progress reflects improvement in a whole range of areas—for example, gathering wider and more useful input, helping with project selection, and increased dissemination and planning for how customers will utilize NIST results and products. ITL has supported this increased focus on its customers by measuring outputs and outcomes that provide data on how the laboratory is doing in this area. (One example is that of tracking the number of times ITL-developed standards and technology are adopted by government and industry.)

Now that ITL is serving its customers so well, the panel wants to suggest that some attention could also be paid to strengthening the laboratory's reputation and stature with its colleagues in relevant research communities. Customers are uniquely positioned to assess the timeliness of and need for ITL results, but ITL's peers can and should assess the technical excellence of the laboratory's work. A variety of reasons support having input from both groups, that is, having a balanced scorecard for the laboratory's portfolio. One reason is that sometimes customer satisfaction is not the right metric, since NIST can, and in some cases should, hold companies to higher standards than the companies might wish. Another reason is that elevating the stature of ITL researchers in their peer communities can raise NIST's credibility with its customers. Therefore, in the future the panel hopes to see increased emphasis on ITL's visibility within relevant research communities.

Increased visibility, such as ITL's successful efforts to improve customer relationships, can be driven by the use of appropriate metrics. It is not entirely clear what outputs or events will effectively measure ITL's work in this area. Possibilities include but are not limited to the number of times that staff are named as nationally recognized fellows of professional organizations (such as IEEE, the Association for Computing Machinery [ACM], the American Physical Society, and the American Society for Quality), the number of times ITL staff are featured speakers at high-profile conferences, and the number of staff publications in top-tier peer-reviewed IT journals. The metrics will obviously depend on the field in which ITL's research is occurring. The panel acknowledges that it is often inappropriate to compare NIST researchers directly with people working in industry research units or at universities, because ITL's role of producing test methods, test data, standards, and so on is different from industrial or academic activities and is often unique. However, ITL's peers at these other institutions are still in a position to recognize and evaluate the technical merit and quality of the NIST programs. The panel is not suggesting that recognition by external peer communities should replace responsiveness to customer needs as a primary focus, but it is instead suggesting that ITL perform the difficult balancing act of putting more emphasis on publication and interaction in the relevant research community without losing its focus on its customers.

Laboratory Resources

Funding sources for the Information Technology Laboratory are shown in Table 8.1. As of January 2002, staffing for the laboratory included 389 full-time permanent positions, of which 319 were for technical professionals. There were also 105 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The panel's primary concern in the area of human resources is the April 2002 retirement of the current director of ITL. 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. A great deal of concern has surfaced among the staff over the process for filling the director's slot, how long it will take, and what the caliber and style of the next director will be. The panel recommends that NIST leadership focus on providing clear communication to staff about the selection criteria and frequent updates as to the progress of the search and hiring process. Sharing relevant information will certainly help the transition proceed more smoothly.

One facilities issue highlighted in last year's assessment report was the location of five divisions in NIST North. The existence and use of NIST North is a perennial issue. The panel recognizes that the

TABLE 8.1 Sources of Funding for the Information Technology Laboratory (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	31.6	31.9	44.4	38.8
Competence	1.5	1.6	1.1	1.3
STRS—Supercomputing	12.1	12.0	11.9	10.0
ATP	1.8	2.4	2.3	2.0
Measurement Services (SRM production)	0.0	0.0	0.1	0.5
OA/NFG/CRADA	8.4	9.9	12.2	14.6
Other Reimbursable	0.5	1.6	1.0	0.3
Agency Overhead	14.4	16.4	18.4	28.2
Total	70.3	75.8	91.4	95.7
Full-time permanent staff (total)[a]	381	381	368[a]	389

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 2001, when it is as of March (due to a reorganization of ITL that year).

quality of the space in NIST North is significantly better than what would be available on campus; however, access to these improved facilities does not compensate for the distance from the rest of the campus for two of the ITL divisions—the Mathematical and Computational Sciences and the Statistical Engineering Divisions. The distance inhibits informal interactions of the staff of these two divisions with their collaborators in the other laboratories on the main campus. Thus, ITL management has submitted the space requirements of these divisions to NIST management, which will be making revised space allocation decisions related to the new Advanced Measurement Laboratory (AML), due to be completed in 2004. The panel encourages NIST management to make a serious effort to move these two divisions back to the main campus.[5] However, 2004 is still several years away. In the meantime, the panel continues to note that a mix of systems taking into account technological and social factors could help compensate for the

[5]One group in the Mathematical and Computational Sciences Division, the Scientific Applications and Visualization Group, is already located on the main campus.

distance. Tools such as videoconferencing, Web collaboration packages, and Web broadcasting can support nonphysical interactions, but 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.

A second facilities issue raised in the 2001 assessment report was the poor network connectivity of NIST to the outside world. The panel was very pleased to learn that since the last review, NIST has joined the Internet 2 project, thus dramatically improving the connectivity and placing NIST on a par with the major universities and industrial research organizations that participate in this project. The next step will be educating researchers in the other laboratories at NIST about how to take full advantage of this new capability.

The panel met with staff in "skip-level" meetings (sessions in which management personnel were not present). The key message from these meetings was that in the past few years, under the current management of the laboratory, ITL has become an especially enjoyable place to work, noted for such attributes as respect for the individual, stability, an appropriate level of flexibility, and focus on visible results. The panel also observed this high level of morale in visits to individual divisions. Turnover in ITL was approximately 9 percent this year, down slightly from last year. Although turnover has decreased in industry in the past year and is now about comparable to that in ITL, over the last several years ITL has had a remarkably low comparative turnover rate for an IT organization. The panel applauds laboratory and division management for creating such a positive work environment.

Some issues were brought up in the skip-level meetings. The panel cannot judge if these concerns are broad-based or isolated but does note that perhaps laboratory management should be aware of them. For example, ITL staff said that while relationships with the other NIST laboratories had improved, they still felt that ITL did not have the same status or prestige that other laboratories enjoy. The panel notes that continued interaction with staff in other laboratories, internal and external recognition of staff, and cross-laboratory projects will help ameliorate imbalances or perceptions of "second-class" status. The shift of IT support services to a separate unit also might help emphasize to the rest of NIST that the core mission of ITL is the same as that of the rest of the laboratories. Other concerns expressed by staff included perceived inconsistencies in performance measurement and some related frustrations about apparently unequal burdens of work owing to the difficult process for firing poor performers in the federal system. Such perceptions, if they indeed exist on a broader scale in ITL, would not be unique to ITL, NIST, government agencies, or even businesses in general.

Laboratory Responsiveness

The panel found that, in general, ITL has been very responsive to its 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 related 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 the improved strategic planning observed in the Mathematical and Computational Sciences Division, the redirection of the work on distributed detection in sensor networks in the Advanced Networking Technologies Division, the transfer of the latent fingerprint workstation to a Federal Bureau of Investigation (FBI) contractor in the Information Access Division, and the work on connecting NIST to Internet 2 in the Information Services and Computing Division. More discussion of responsiveness and of areas needing continued attention is presented in the divisional reviews below.

In some areas, the issues raised by the panel are long-term questions or areas in which changes are not entirely within ITL's power. In these cases, the panel looks to see if serious effort has been made. Usually the panel observes some progress and plans to follow up on the issues in future assessments. The location of the MCSD and SED Divisions in NIST North is one such issue, and while the panel is glad to learn that their relocation in conjunction with the occupation of the AML is being considered, the panel will be watching to see whether this occurs and how ITL handles the time prior to AML's completion. Another such issue is the growing use by industry of consortia and other private groups to set industry standards. The panel recognizes that this trend cannot be controlled by ITL, but it would like to see further consideration of internal policies on use of closed consortia and of ways to encourage open standards development.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- The panel is impressed with the progress that has occurred in strategic planning in the Information Technology Laboratory (ITL), particularly in the emergence and acceptance of a framework under which laboratory activities operate. The framework includes an ITL Research Blueprint and ITL Program/Project Selection Process and Criteria.
- ITL has done a remarkable job of becoming more customer-oriented over the past several years. The panel applauds the laboratory's efforts in outreach and notes that the progress reflects improvement in a whole range of areas, from gathering wider and more useful input to help with project selection to increased dissemination and planning for how customers will utilize NIST results and products.
- The strong customer relationships now need to be balanced by robust visibility and recognition in ITL's external peer communities. Publications in top-tier journals, presentations at high-profile conferences, and awards from ITL's peers will help confirm the technical merit of the work done at NIST and will add to the laboratory's credibility with its customers.
- Conveying awareness of the social issues related to ITL's technical work in areas such as biometrics is an important element of the credible presentation of ITL results to diverse audiences. In certain areas, considering the technical and social context of how the work will be used may help focus the research on the most appropriate questions.
- The shift of the information technology (IT) support functions to a new unit reporting directly to the NIST director is an opportunity and a challenge for NIST leadership. If this new unit can convince the NIST laboratories to embrace consistent, institutionwide standards for IT systems, it will be an important step and a major cultural shift at NIST. Appropriate emphasis is being placed on demonstrating how IT services can facilitate research and how standardizing basic applications can save time and money.
- The retirement of the current director of ITL is clearly a source of concern within the laboratory. The panel recommends that NIST leadership focus on communicating clearly with staff about the selection criteria for the director's replacement and that it supply staff with frequent updates on the progress of the search and hiring process. Sharing of relevant information will certainly help the transition proceed more smoothly.

DIVISIONAL REVIEWS

Mathematical and Computational Sciences Division

Technical Merit

The mission of the Mathematical and Computational Sciences Division is to provide technical leadership within NIST in modern analytical and computational methods for solving scientific problems of interest to U.S. industry. To accomplish this mission, the division seeks to ensure that sound mathematical and computational methods are applied to NIST problems, and it also seeks to improve the environment for computational science at large. Overall, the panel is very impressed with the quality of the division's work and the strength of its collaborations with other divisions and laboratories at NIST. The division is on track in its execution of a large, ambitious project—the Digital Library of Mathematical Functions (DLMF)—and it is becoming deeply involved in a strategic NIST-wide project on quantum computing. The panel also observes that the division's strategic planning process is strong and that it is improving.

The Mathematical and Computational Sciences Division is organized in four groups: Mathematical Modeling, Mathematical Software, Optimization and Computational Geometry, and Scientific Applications and Visualization have common themes, such as better mathematical models, better solvers, application of parallelism, and the development of reference implementations and data sets. The projects are mostly collaborative, with collaborators chosen from other NIST laboratories and from external organizations. The division's overall portfolio is a balanced mixture of short-term and long-term projects and of projects with small and large numbers of staff. Last year's assessment report raised some questions about the division's project selection process and strategic planning, and this year the panel was impressed to see that significant progress had been made in this area. The division has a number of ongoing planning activities at division, laboratory, and NIST-wide levels, and it now has a good mixture of bottom-up and strategically generated projects. The triennial update of the division's strategic plan is scheduled for later in 2002, and the panel looks forward to reviewing the revised plan in next year's assessment.

The work on the Digital Library of Mathematical Functions is a good example of the focus on reference materials that makes the division's products so useful to a broad array of customers. The goal of this ambitious project is to provide a Web replacement for the classic National Bureau of Standards publication *Handbook of Mathematical Functions* by Abramowitz and Stegun.[6] The DLMF will be extremely important to scientists and engineers who need access to the latest tools and algorithms related to special mathematical functions, and this work is precisely in line with the division and NIST missions. The division has formulated a good strategy for developing the DLMF; it is using outside editors, attracting external funding (the division was awarded a competitive grant from the National Science Foundation for this project), attracting internal NIST funding, and developing a single writing style to be used in all chapters. Each chapter includes mathematical properties, methods of computation, and graphs, among other useful information. In the past year, progress on DLMF has continued at a good pace; drafts are now available for much of the work, and validation of the information is taking place. The current schedule calls for formal public release of the completed library in 2003, at which

[6] M. Abramowitz and I.A. Stegun, eds., *Handbook of Mathematical Functions, with Formulas, Graphs, and Tables,* Applied Mathematics Series 55, National Bureau of Standards, Washington, D.C., 1964.

time the panel expects the DLMF Web site to become one of the most popular mathematical Web sites in the world. In the upcoming year, the critical challenges for this project are not primarily technical, but relate more to program management, as the impending deadlines require a significant amount of editorial and production work. The panel hopes that NIST will allow staffing levels to remain sufficient to ensure a high-quality final product.

An example of the division's effective work in mathematical modeling is the work on Object Oriented Micromagnetic Framework (OOMMF). The goal of this project is to provide a platform for two- and three-dimensional modeling of magnetic phenomena associated with magnetic storage media. (The two-dimensional code is complete, but work is still under way on the three-dimensional version.) The code is written to be highly configurable; it uses Tcl/Tk to provide easy scripting capabilities and cross-platform graphical user interfaces, and the solvers are open-source C++. In 2001, 11 papers were published using results generated by OOMMF.

An impressive new project is the work on quantum information processing. This "hot" area is attracting a great deal of attention from the research community, and the panel believes that NIST is well positioned to have an impact here, owing to NIST's Nobel Prize-winning physicists, who have expertise relevant to quantum computing, and to the strength of the Mathematical and Computational Sciences Division both in continuous modeling and simulation and in discrete algorithms.

The work on mathematical modeling of solidification is an excellent example of how the applied mathematicians in the Mathematical and Computational Sciences Division can effectively leverage their expertise to produce significant impact from their consulting and collaborative roles. In this project, one division staff member has teamed up with about six dozen people from the NIST MSEL and a large group of university colleagues to model electrodeposition in support of experiments in this area, to model interfacial instabilities during the cooperative growth of monotective materials, and to develop models of solid-state order-disorder transistions. The staff member from the Mathematical and Computational Sciences Division was elected a fellow of the American Physical Society for his work in the area. Another example of a successful collaborative project is the work on machining process metrology, in which a researcher from this division is working with 10 people from three other NIST laboratories (MSEL, MEL, and PL).

The Scientific Applications and Visualization Group joined the Mathematical and Computational Sciences Division last year, relocating from another division within ITL. This group has a strong positive impact through its collaborations with NIST scientists who require state-of-the-art algorithms and architectures to get the performance they need from their scientific codes. As the sheer volume of data in scientific computations increases, visualization techniques become increasingly essential in order for results to be effectively utilized and interpreted. This group has an excellent combination of a wide range of technical skills and a strong collaborative style, as demonstrated particularly by the cluster of projects around concrete modeling. The group also has a strong role in creating standards; for example, a few years ago it facilitated the development of an Interoperable Message Passing Interface (IMPI) standard, and this standard is now having an impact on commercial software.

Program Relevance and Effectiveness

The Mathematical and Computational Sciences Division staff is well connected, well published, and influential on organizing committees and editorial boards. Their work is well regarded by customers both inside and outside NIST. All of the division's projects have an excellent record of dissemination of results, through a variety of mechanisms such as software, publications, Web services and documentation, conference talks, and workshops. A key factor in the success and impact of the division is the high quality of the staff. Overall, the technical excellence of the division's staff is demonstrated in a variety of ways. Personnel receive numerous internal and external awards (including two elections to professional society fellowships in 2001); the division continues to produce a significant number of refereed publications and invited talks; staff serve as editors for many journals (including ACM *Transactions on Mathematical Software,* for which the division chief is editor-in-chief); and division personnel fill many senior leadership positions in professional societies and working groups and on conference organizing committees.

Last year, the panel cited the Java Numerics project as an excellent example of work with impact and vision and as a good use of NIST's scientific leadership role. Clearly NIST agrees, as the leaders of the project were awarded the NIST Bronze Medal in 2001. In 2002, this project continues to produce important results. Another impressive project that supports NIST's core mission is the work on Sparse Basic Liner Algebra Subprograms (BLAS). As with Java Numerics, this work on mathematical software standards is able to impact the commercial landscape owing to the high quality and reputation of the division's scientists.

Last year's assessment report discussed the importance—as an element of maintaining the reputation of NIST scientists—of supplementing the many articles coauthored by division staff and appearing in the journals of their collaborators' fields with publication in their own disciplinary journals. The division's FY 2001 annual report[7] lists the publications that appeared or were accepted in refereed journals this past year; about 12 are in journals in mathematics, scientific computation, or visualization, another 20 or so are in journals in other disciplines, and the last handful are harder to categorize. This represents a balance between the division's mission of consulting and collaboration and the need for its staff to be recognized as leaders in the mathematical and computational research communities. The former requirement should not be allowed to overshadow the latter one, and the panel encourages the division to maintain and in some cases to raise its visibility at premier mathematical and computational conferences in the areas of division expertise. For example, several projects in the division have a significant component involving computational geometry. The division therefore could consider raising its profile at the annual ACM Symposium on Computational Geometry. Familiarity with the journals and activities in these fields is an important factor in identifying opportunities, and the panel was pleased to learn that the availability of online journals is easing somewhat the problems noted last year with maintaining the NIST library's journal collections.

Since the terrorist attacks in September 2001, a variety of programs at NIST have been affected by the federal government's changing priorities. In the Mathematical and Computational Sciences Division, some research projects will probably achieve a higher profile because of their relevance for homeland security. Examples include the projects on image processing and on laser radar (LADAR) systems, both of which will help protect the safety of first responders to terrorist events or other disasters. The division and ITL are participating in NIST-wide planning for activities connected to homeland security and counterterrorism. Indirect effects, such as increased budget uncertainty at various government agencies with which the division works, will also have an impact on the division.

[7]U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Mathematical and Computational Sciences Division Summary of Activities for Fiscal Year 2001*, National Institute of Standards and Technology, Gaithersburg, Md., January 2002.

TABLE 8.2 Sources of Funding for the Mathematical and Computational Sciences Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)[a]	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	3.3	3.6	4.1	7.2
Competence	0.2	0.2	0.1	0.1
STRS—supercomputing	0.7	0.6	3.4	0.6
ATP	0.1	0.1	0.5	0.5
OA/NFG/CRADA	0.4	0.7	0.9	1.9
Other Reimbursable	0.0	0.1	0.0	0.0
Total	4.7	5.3	9.0	10.3
Full-time permanent staff (total)[b]	30	27	39[b]	39

NOTE: Sources of funding are as described in the note accompanying Table 8.1.

[a]The difference between the FY 2000 and FY 2001 funding and staff levels reflects the reorganization of ITL, in which the Scientific Applications and Visualization Group was moved out of the Convergent Information Systems Division and into this division.

[b]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

Division Resources

Funding sources for the Mathematical and Computational Sciences Division are shown in Table 8.2. As of January 2002, staffing for the division included 39 full-time permanent positions, of which 36 were for technical professionals. There were also 15 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

Resources in the division are tight, and the panel is concerned about several effects, related mainly to the constraints on the number of permanent staff, which has been basically constant for several years (the rise in Table 8.2 is due to an organizational change in which a new group was added). In this environment, the division has not been able to hire permanent staff to address continuing and emerging needs in computational science at NIST. One such area is quantum computing, where the division cannot recruit new permanent staff and is instead making good use of outside consultants and collaborators and a new postdoctoral research associate in this area. Traditional areas that are also short-staffed include numerical analysis, mathematical software, and optimization. The panel is particularly concerned about the situation in the Mathematical Software Group, where staffing constraints have limited the group's ability to explore new projects and forced several existing projects into "maintenance mode." While the ongoing work in the group is all meritorious, the panel believes that the group is being stretched dangerously thin.

One factor affecting the division's ability to hire new staff is the virtual lack of attrition recently among permanent staff. This lack of turnover reflects the high morale observed in the division. The panel found that individual researchers are enthusiastic about their work and their management. Staff praised laboratory management's fostering of good communications both horizontally and vertically; the panel notes that this is quite a change from 3 years ago, when morale problems were severe. Indeed, many positive comments were made about the entire laboratory and division management chain during the panel's meetings with individual staff members. Taking the rarity of new hires to permanent staff as a given, management has made effective use of affiliated faculty at area universities and of postdoctoral research associates. Unfortunately, space in this division is tight, limiting the possible number of summer visitors.

Given the many demands on personnel's time in the current environment, the division must make careful decisions about when and how to develop new revisions of software packages. In many current software projects, the developers are working on a new release for an already successful package. The panel believes that the strategic goals of the division should be taken into account when deciding the priorities with respect to which packages receive new releases. In particular, the panel encourages the division to develop a set of criteria on which to base decisions concerning the time at which work on a second release should begin and what the goals of the release should be. Such criteria should emphasize how the second release would promote the overall mission and goals of the division. In some cases, the decision may be that the most strategic use of resources would be to cease further development on one package and move to a new project.

Another area in which the division needs to be careful about effective deployment of staff time is the long-term maintenance of Web resources such as the Guide to Available Mathematical Software (GAMS), Matrix Market, and the Template Numerical Toolkit (TNT). The division has a huge Web presence (which the panel applauds), and this presence is bound to increase with the release of DLMF and other projects. Many traditional NIST activities produce standard reference data or materials, which are then distributed to customers by NIST's Office of Measurement Services. This static model is not a good fit to the Mathematical and Computational Sciences Division's standard information resources, but the division would certainly benefit from a new approach that allowed the research groups to be relieved of some of the more mechanical tasks required to maintain these resources on the Web. A solution to this problem is not obvious, because proper, long-term maintenance of resources such as DLMF requires the attention of a mathematician (not just a Webmaster), yet this mathematician's time might be better spent on new projects. Indeed, finding a balance between providing useful and up-to-date technical information on the Web and having time to develop new research activities is an issue for most scientific and research organizations that post technical Web pages, and NIST can provide leadership in this area. As a first step, the panel suggests that the division think about the factors that might go into deciding at what level to carry out long-term maintenance of Web pages and that it develop a policy governing these decisions.

As has been noted in many past reports, the housing of most of the division at NIST North makes informal interaction between division staff and personnel on the main campus difficult. This is a significant disadvantage for the division, as collaborative efforts with other NIST laboratories are a primary focus. Once a collaboration has begun, the physical distance is only an inconvenience, but many new collaborations, especially those in new areas, originate from casual contacts that are not currently available to the staff at NIST North. Increasing the difficulty of discovering new areas for cooperative work may have negative long-term impacts on the vitality of the division's project mix. A related concern is that the division's new group, Scientific Applications and Visualization, is currently located on the main campus, not in NIST North, and the panel did not observe much interaction between this group and the rest of the division, probably because of the physical separation. Another locational issue is the relationship between the division's Gaithersburg personnel (which include division management) and its small group at NIST Boulder. Some of the Boulder staff have expressed a desire for closer connections with the rest of the division. Division management should consider mechanisms to increase Boulder-Gaithersburg interactions, such as a small dedicated travel fund for staff travel between the two sites. It would also be useful to have some Boulder staff travel to Gaithersburg for the annual assessment of the division.

Advanced Networking Technologies Division

Technical Merit

The mission of the Advanced Networking Technologies Division is to provide the networking industry with the best in test and measurement technology. This mission statement is appropriate, and it accurately reflects the NIST and laboratory missions within the context of technologies relevant to this division's work. The division focuses on using test and measurement technologies to improve the quality of networking specifications and standards and to improve the quality of networking products based on public specifications. In emerging technology areas, the division also performs modeling and simulation work to help ensure that specifications produced by industry and standardization organizations are complete, unambiguous, and precise. The panel finds that the division's activities over the past year are definitely relevant and effective and that the programs encompass several of the currently important areas in networking research.

The work of the Advanced Networking Technologies Division is of consistently high quality, and the panel is pleased to see that the incremental improvements observed over the past 3 years are continuing. The organization of ongoing programs around coherent research themes has produced good synergy and allowed more communication and collaboration among the research groups. The themes also provide continuity as projects are completed and new activities initiated.

The Advanced Networking Technologies Division consists of three groups: High Speed Network Technologies, Wireless Communication Technologies, and Internetworking Technologies. Currently, the division's work is organized in six projects: Networking for Pervasive Computing, Wireless Ad Hoc Networks, Agile Switching, Internet Telephony, Internet Infrastructure Protection, and Quantum Information Networks. These projects are generally well focused on achieving specific and valuable goals and are well directed in support of the NIST mission. The panel is particularly pleased by the balance among the projects: half are driven purely by needs of relevant external communities, and half are projects coordinated across ITL and other NIST laboratories. A good mix of time scales also exists, as two projects are aimed at having short-term impacts, three at intermediate-term effects, and one at long-term goals. Below, the panel describes some of the highlights and issues observed in its assessment of the division's activities.

A great many activities are under way in the Networking for Pervasive Computing area. Two of these activities are aimed at supporting the development of networking standards for relevant devices. The first focuses on issues surrounding how to craft the various ubiquitous wireless standards (e.g., IEEE 802.15 and IEEE 802.11) so that they do not conflict within the unlicensed 2.4-GHz band. The original designers of the relevant standards all assumed that simply by complying with Federal Communications Commission (FCC) regulations for operation in this band, their technology would not conflict with the operation of other radio technologies sharing the spectrum. However, it has now become clear, largely through work done in the Advanced Networking Technologies Division, that successful coexistence will almost certainly require more than compliance with FCC regulations, and NIST has taken an important leadership role on questions related to reconciling the standards. Division staff have extended their earlier work on formal modeling of Bluetooth and simulation of the interactions between it and IEEE 802.11, and they are now developing tools to assess the effectiveness of various methods of coexistence, including synchronized receivers and combined radios. These results are valuable, and the panel is particularly impressed with how aggressively and effectively the division tackled the problem. The timely information coming out of NIST will allow the IEEE (Institute of Electrical and Electronics Engineers) groups to incorporate the division's solutions into the standards. The second effort in the area of networking standards for pervasive computing devices focuses on the analysis of the resource discovery protocols being developed for ubiquitous computing systems. Current efforts include work on modeling service descriptions for Jini and Universal Plug and Play (UPnP). The panel continues to be impressed with this activity and suggests extending the work to the Internet Engineering Task Force Service (IETF) Location Protocol.

The Wireless Ad Hoc Networks project was formed this year by combining the division's work on technologies and standards for mobile ad hoc networks (MANETs) and for smart sensor networks. The work on MANETs encompasses both analysis and simulation. While developing the simulations, division staff evaluated the effectiveness of two popular simulation environments, OPNET and NS. Thus, one valuable outcome of the project is a forthcoming report comparing the usefulness of these two environments for simulating MANETs; this information should help drive the future evolution of these simulation tools. The division's research on MANET routing criteria focuses on Kinetic Spanning Trees and clustering structures; this new activity has considerable promise and is well aligned with current work in this field outside NIST. In the smart sensors area, the work on distributed detection in sensor networks has been redirected into investigating networking protocols and distributed algorithms for support of sensor networks, as suggested by the panel in last year's assessment.

In the Agile Switching project, the division has completed its project on modeling, evaluation, and research of lightwave networks (MERLiN). This year's focus is now on extending the work to multilayer restoration multiprotocol label switching (MPLS) optical restoration and recovery. As part of this work, division staff developed a modeling tool called GHOST, which promises to have wide utility in research and in industry for analyzing approaches to restoration and recovery. In addition to developing this tool, staff are also using GHOST to investigate various aspects of restoration, particularly those involving large-scale failures and multiple simultaneous failures. A new facet of this project is the work on extending GHOST to allow the investigation of the interaction between failure/recovery and quality of service-based traffic engineering; this effort promises to produce valuable results by next year's assessment. The panel notes that integrating and aligning the new project on game theoretic approaches to analyzing failure and restoration with the work on extending GHOST would benefit both projects.

The past year has seen a great deal of progress in the project on Internet Telephony (voice over Internet Protocol [IP]). The staff spent the first year of this project (2000) learning the technology and building an interesting set of diagnostic and testing tools for session initiation protocol (SIP)-based call signaling. The development of such an interoperability test tool is valuable to the community, and the Web-enabled SIP load generation and trace capture elements of this tool are already demonstrating their utility by helping implementers tease out subtle interoperability problems. Now that the basic pieces of this project have achieved critical mass, the panel suggests that it would be advantageous to expand the effort to include the associated protocol machinery that surrounds basic call signaling (such as telephony routing over IP, telephone number mapping, and call routing). Addressing questions related to the other elements around SIP-based call signaling would significantly enhance NIST's contributions in this area.

In early 2001, the Advanced Networking Technologies Division completed its valuable work on developing reference implementations for Internet Protocol Security (IPsec). Now the emphasis has shifted to Internet infrastructure protection, in particular to the protection of the Domain Name System (DNS) via DNSsec. This important project is a collaborative effort with the Computer Security Division, and the panel believes that the focus on DNSsec is appropriate. While DNSsec has not enjoyed wide adoption to date, recent events have raised the general awareness about the need to protect shared

Internet services such as the DNS, and hence the impact of NIST's work in this area should be higher in the future. The division has also begun a new project on evaluating the performance and scalability of IPsec key management protocols. This timely work should help inform the IETF's ongoing effort to select a successor to the Internet Key Exchange (IKE) key management protocol. The panel also urges the division to be alert to potential new issues in high-performance IPsec extensions that are expected to arise in the next year or two.

As part of the NIST-wide initiative in quantum computing, the Advanced Networking Technologies Division is working with the Computer Security Division on protocols and prototypes for quantum cryptography. The Advanced Networking Technologies Division's contribution, known as the Quantum Information Networks project, is in the area of key management protocols for quantum key distribution. The panel is pleased to see that this project has both a protocol design and a prototyping element using a real quantum channel. This project is associated with the IPsec key management protocols work mentioned above, and the panel expects that good synergy should be achievable across the two areas. While the practical impact of the Quantum Information Networks work is too far in the future to predict, having a few such long-term projects provides a good balance to the division's overall research program. In addition, the division is able to contribute to a NIST-wide program, thus keeping researchers and management engaged in NIST's overall mission.

In summary, the panel is very pleased with the division's ability to sunset activities either because the stated goals have been accomplished or because technical innovations require a shift in focus. Programs concluded this past year include the development of reference implementations for IPsec, the MERLiN project, the broadband wireless work on IEEE 802.16, the 3G cellular work, and the active network project, which has been shifted to the technology transfer stage. The division has also demonstrated impressive agility and the ability to jump into an area early and to select work with significant potential impact. Between the 2001 and 2002 assessments, the division used project mergers and conclusion to move from nine projects to six (one of which is entirely new). This consolidation helps highlight synergies between activities and helps reduce the number of projects with just a few staff members working on them. The panel is also impressed with the closer collaborations that have developed between staff working on different projects; specific examples of effective cooperative pairings include that of optical restoration modeling and MPLS and that of sensor networks and MANET. Utilization of the expertise and results available in other groups within the division is a constructive way to leverage a project's resources and maximize NIST's impact.

Program Relevance and Effectiveness

Staff of the Advanced Networking Technologies Division continue to be active in a variety of industry organizations, including the IETF, the IEEE, and the International Telecommunications Union. NIST 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 are 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. NIST'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 space on which the standards bodies should be focusing. One example of recent impact is the division's notable success at raising the visibility of co-interference problems between IEEE 802.11 and Bluetooth wireless networks. Current efforts with the potential for significant future impact include the work on SIP interoperability testing, which is likely to help tighten the specifications and arbitrate interoperability disputes, and the work on understanding the dynamics of resource discovery protocols, which may help improve existing solutions such as UPnP and Jini, while potentially showing the benefits of more general and standards-based approaches such as Service Location Protocol.

In the 2001 assessment, the panel discussed at length the growing practice of industry to develop standards in consortia or other private grouping rather than through the traditional "open" approach of mainly utilizing professional organizations. The situation has not changed since last year, and the issue remains important. The panel, and the division, recognize that the "closed" system is somewhat antithetical to the NIST and governmental philosophy of supporting all U.S. companies and the public in an open manner. However, to carry out the NIST mission of strengthening the U.S. economy, the division must be able to impact the standards that will be used in the networking community no matter how they are developed. Therefore, NIST should develop a policy on this issue, together with criteria for deciding when and how to participate in these consortia. Some of the closed standards groups are actually very inclusive, with minimal burdens placed on participants; others may be designed to exclude potential competitors and should not be endorsed by NIST. Therefore, NIST should also consider whether it could develop a strategy for encouraging the IT community to continue to utilize open, or at least quasi-open, models of standards development.

The Advanced Networking Technologies Division assumes a leadership role in the networking communities, in part by virtue of the standards activities described above. However, it is important for the staff to build awareness of NIST's expertise and to maintain its reputation in other ways. The division does publish in journals and conference proceedings, and its personnel attend a variety of meetings. These activities are highly appropriate, but the panel suggests that a larger presence in the more prestigious publications and conferences of the networking field might be appropriate. Stronger and more visible participation in the top tier in these areas would provide the widest dissemination and enable the greatest impact for NIST results. It would also allow the division to burnish its reputation, develop the reputations and visibility of its most respected staff, and position itself as a key element of the networking community.

Division Resources

Funding sources for the Advanced Networking Technologies Division are shown in Table 8.3. As of January 2002, staffing for the division included 24 full-time permanent positions, of which 20 were for technical professionals. There were also 10 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The primary issue for the Advanced Networking Technologies Division is its limited number of full-time permanent staff. The division performs relevant and effective work, in part because of a large cadre of guest researchers (20 people as of February 2002). This heavy reliance on visitors means that the division depends on temporary employees to support the mission-critical projects, and the potential exists for unexpected delays or the premature termination of an important effort when a guest researcher leaves NIST. The panel believes that these risks are currently outweighed by the benefits provided by the added manpower 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. Similarly, caution should be exercised about the balance between internal and external funds.

The panel was pleased to observe that morale within the division is quite good and that the staff is enthusiastic about its work. This year's transition in leadership (a new division chief) was accomplished very smoothly, with no disruption in focus or loss of momentum. Division and laboratory management

TABLE 8.3 Sources of Funding for the Advanced Networking Technologies Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	4.9	4.0	4.1	4.6
Competence	0.2	0.3	0.2	0.2
ATP	0.3	0.5	0.3	0.2
OA/NFG/CRADA	1.2	1.7	1.5	2.2
Total	6.6	6.5	6.1	7.2
Full-time permanent staff (total)[a]	30	27	21[a]	24

NOTE: Sources of funding are as described in the note accompanying Table 8.1.
[a]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

should fill the position of High Speed Network Technologies Group leader soon to allow the acting group leader to focus his attention on his new responsibilities as division chief.

Computer Security Division

Technical Merit

The mission of the Computer Security Division is to improve information systems security by:

- Raising awareness of information technology risks, vulnerabilities, and protection requirements, particularly for new and emerging technologies;
- Researching, studying, and advising agencies of IT vulnerabilities and 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, to educate consumers, and to establish minimum security requirements for federal systems; and
- Developing guidance to increase secure IT planning, implementation, management, and operation.

The division's programs directly support this mission and are consistent with the mission of the Information Technology Laboratory and of NIST. Privacy and security are essential to protecting electronic commerce, critical infrastructure, personal privacy, and private and public assets, so this work makes important contributions to strengthening the U.S. economy and promoting the public welfare.

The programs under way in the Computer Security Division are highly appropriate, and the division's work has great technical merit. After a reorganization, the division is now composed of four groups: Security Technology, Systems and Network Security, Security Management and Guidance, and Security Testing and Metrics (the last two groups are new).

The Advanced Encryption Standard (AES) continues to be the focus of the Security Technology Group. In August 2001, NIST hosted a second workshop to continue to facilitate the analysis and development of new modes of operation for AES.[8] NIST staff are also developing test and validation suites for the applications of AES. The open design of the AES, and the competition used to select it, have greatly enhanced the reputation of the division and are a model for future standards work.

The Systems and Network Security Group is working in a broad range of areas, including emerging technologies, reference data and implementations, and security guidance. One project is aimed at providing the technical support necessary to create a ubiquitous smart card infrastructure in the United States. Specific NIST efforts include the development of automated test suites and a testbed for the Government Smart Card Program, as well as the development of architectural models and security testing criteria. This work is appropriate because it will enable the development of consistent test methodologies for smart cards and will also reduce their cost and encourage their use in many areas. Another ongoing activity in this group is the ICAT Metabase, which is a searchable index of computer vulnerabilities that links users to a variety of publicly available vulnerability databases and patch sites. By integrating ICAT with other standard lexicons, such as the Common Vulnerabilities Enumeration, division staff have made this resource invaluable to industry as well as to researchers and users of computer systems.

Another activity in the Systems and Network Security Group is the work related to security on mobile devices, such as personal digital assistants (PDAs). The goal of this work is to develop new security mechanisms for wireless mobile devices so that the devices can be used as smart cards or computation devices to validate information about the possessor. While this objective is clearly appropriate for this division, the panel is concerned about the direction of the project and is not convinced that the work will prove fruitful. Securing hand-held PDAs is important, indeed critical, when the owner of the PDA is trying to protect information on the PDA. However, if the owner is untrusted, and a third party places information on a PDA that is to be used later as a security token (for whatever purpose), an untrusted party then has access to that information and can read, alter, and/or delete it. More specifically, securing the information would require that the PDA be a reference monitor, which it is not. The division should recast the work with this observation in mind.

A relatively new effort in the Systems and Network Security Group is a project on defending public telephone networks, including analysis of signaling system seven (SS7) vulnerabilities. The scope of this project is not clear to the panel. It might address basic communication security, application-specific security requirements for SS7, or both. The former area can be addressed via underlying communication protocol security mechanisms, such as the use of IPsec when SS7 is carried over IP. Concerns in the latter area are intrinsic to SS7 and have been studied by telephone companies in the past. For example, in the early 1990s, GTE Labs developed an SS7 "firewall" to protect central office switches. Before embarking on this project, division staff should be familiar with previous work in this area, not all of which has necessarily been widely published. Thus, the panel recommends that division staff contact the research groups that have worked in this area, such as the Verizon Technology Organization (which houses the former GTE Labs), Telecordia (formerly Bellcore), and the National Communication System technical staff, in order to become familiar with previous work in the area of SS7 security and countermeasures.

Work in the new Security Management and Guidance Group is entirely appropriate, and the group's goal of advising and assisting government agencies is laudable. The panel felt that, on the whole, the

[8]A mode of operation, or mode, for short, is an algorithm that features the use of a symmetric key block cipher algorithm to provide an information service, such as confidentiality or authentication.

programs under way to implement these goals are very suitable for the division and have high technical merit. A primary focus is the Computer Security Resource Center, a valuable Web site that provides information about computer security for the public.[9] This Web site is accessed by a wide range of organizations, including federal agencies, businesses, and schools, and exemplifies how the division can effectively make information available and accessible to a broad audience. The maintenance of this site is consistent with the division's mission, as is the work on outreach to both federal agencies and businesses. These activities serve both to educate the public about computer security and to provide resources that the public can use.

One of the key programs in the new Security Testing and Metrics Group is the National Information Assurance Partnership (NIAP) program, which 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. The goal of this work is to enable quicker, more effective security evaluations and to standardize baseline security requirements for particular environments and products. In the past year, six Common Criteria testing laboratories have been accredited, and work is proceeding on the development of new protection profiles (such as for financial institutions). Fourteen nations have now signed mutual recognition testing agreements (recognizing the Common Criteria and the Common Criteria testing laboratories).

Another cornerstone of the Security Testing and Metrics Group is the work on cryptographic security testing and cryptographic module validation. A variety of efforts contribute to these projects, including work on public-key infrastructure (PKI) standards, components, and committees. One goal of this work is to enable businesses, citizens, and organizations to interact with the government over the Internet. Originally, the plan was to develop a single portal for this "e-government" program, but, unfortunately, the lack of funding in 2002 for integrating authentication into this project seriously weakened its viability.

The NIAP and the Cryptographic Module Validation Program are important components of the Security Testing and Metrics Group. While both programs are consistent with the group's overall objective of improving the security and quality of IT products through development and use of metrics and tests, the panel feels very strongly that under no circumstances should the NIAP and the CMVP be merged. The CMVP has a quantitative focus and aims to provide automatic measures of compliance, while the Common Criteria (the basis for evaluations under the NIAP) is qualitative and is not susceptible to the quantification that the CMVP uses. The customers of the two validation processes, and the goals of those processes, differ significantly, and merging them would be detrimental to both.

Program Relevance and Effectiveness

The Computer Security 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 facilitates the development of new and more effective security techniques. Division staff disseminate their results through publications, presentations, advice to government agencies, participation on committees, and posting of tools, databases, and information on the Web. The result is enhanced IT security through wider availability of products that meet security standards.

[9]The Computer Security Resource Center is available online at <http://csrc.nist.gov/>.

One example of the impact of this division's programs is the way that the CMVP improves the security and quality of cryptographic products. Of 164 cryptographic modules tested, about 50 percent had security flaws, and over 95 percent had documentation errors. Of 332 algorithm implementations submitted for validation, about 25 percent 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 is a sterling example of what the division is and should be doing to carry out its mission.

In addition to developing cryptography and security standards and tools, division staff are active in several national and international standards activities and in groups such as ANSI, ISO, and the IETF. The committees and activities of these organizations are examples of open standards development and adoption environments. In last year's report, the panel discussed the issues related to the growing number of cases of industry's developing and choosing standards in closed or exclusionary groups, such as some consortia. The panel emphasized that the division must take care not to endorse specific protocols developed by companies outside open standards environments. Instead, the division should aim to sanction only standards that resulted from open development processes, such as processes within inclusive standards organizations or at NIST itself. When flaws in a standard are found, the standard must be fixed, but the panel was concerned that exclusive standards processes make it easier for companies to argue against fixing the standard when the change would delay the deployment of a new product or interfere with products already on the market. NIST cannot be party to such behavior.

The panel continues to worry about the potential that such problems will arise with standards developed in closed settings, and it continues to recommend that only standards arrived at openly be endorsed by the Computer Security Division. This year, the panel's concerns have broadened slightly, particularly in light of the deference occasionally shown by NIST to the vendor communities. The issue arose in the context of the division's work on best practices, as well as in the division's development of protection profiles for the Common Criteria. NIST can and should use industry standards and methodologies, but they should be standards and methodologies that have been carefully developed, thoroughly studied, and extensively tested, and it should be verified that the standards and methodologies are not merely appropriate but are the best with respect to the performance goals they are designed to produce. Thus, standards and methodologies from industry should not be adopted unless NIST verifies that these criteria are met.

Division Resources

Funding sources for the Computer Security Division are shown in Table 8.4. As of January 2002, staffing for the division included 48 full-time permanent positions, of which 42 were for technical professionals. There were also 17 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The funding for the Computer Security Division is dropping dramatically in FY 2002, almost entirely because of the decision by Congress and the administration not to continue funding two large programs housed in this division: the Computer Security Expert Assist Team (CSEAT), which was funded at $3 million in FY 2001, and the Critical Infrastructure Protection (CIP) Research and Development Grants Program, which was funded at $5 million in FY 2001. In light of recent events, the panel is particularly appalled at the reduction in funding for computer security activities. This is a time of heightened concern about the potential vulnerabilities of the nation's computers and networks, and the division has the technical expertise to make major contributions to the protection of computer and infrastructure systems. Congress and the administration should use and expand that expertise rather

TABLE 8.4 Sources of Funding for the Computer Security Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	5.9	6.6	17.6	9.7
ATP	0.2	0.3	0.4	0.0
OA/NFG/CRADA	2.3	1.4	2.1	1.1
Other Reimbursable	0.1	0.1	0.0	0.0
Total	8.5	8.4	20.1	10.8
Full-time permanent staff (total)[a]	48	43	40[a]	48

NOTE: Sources of funding are as described in the note accompanying Table 8.1.
[a]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

than ignore or reduce it. Legislation proposed in the spring of 2002 seems to ignore or bypass NIST, which is detrimental to the morale and wasteful of the expertise available in the Computer Security Division.

One risk from the reduction of the congressionally allocated internal (STRS) funding is that the division may be forced to rely more on external (OA/NFG/CRADA) funding. This type of support is usually tied to particular projects that are of interest to the outside funding agency. When the division has less control over the scope and direction of its overall portfolio of activities, morale suffers, and the staff's ability to support the missions of the division, ITL, and NIST is compromised. Thus, the division should be careful to accept external money only for projects that contribute to, complement, and enhance the division's ability to meet its overall objectives. The panel is very concerned about this issue, and it recommends that the division be careful to avoid obtaining external funding unless it is justified by reasons other than just keeping people on staff. The panel does note that the division chief has shown exceptional initiative in investigating other potential sources of income for the division, such as charging customers for cryptographic module validation. While a system for such fees has not been successfully determined, it is an appropriate avenue to explore; if the services provided by NIST were provided by a commercial testing company, the customers certainly would not get them for free.

In the discussion of Computer Security Division resources in the 2001 assessment report, the panel expressed concerns about two programs: CSEAT and the CIP Grants Program. While funding for NIST for both of these programs has been eliminated in FY 2002, before that time the division had been very responsive to the panel's concerns, and the panel commends the division for its efforts. In the first area, the concern related to the focus of CSEAT. The panel recommended that CSEAT's scope be retargeted to support training and education rather than maintaining its initial focus of developing a capability for penetration studies for other government agencies. The panel was pleased that this shift did occur, and that last year, CSEAT reviewed policies and provided guidance to federal agencies and high-risk computer security programs. Of course, without funding, these activities will cease. In the second area, the panel indicated its belief that the current level of funding for the CIP Grants Program (in FY 2001, $5 million was to be distributed in grants) was too small to have an impact. Numerous grants funded at low amounts can provide neither the breadth nor the depth of research required to make meaningful contributions to the massive and complex problem of how to secure the nation's critical infrastructure. The division was responsive to this observation, and the panel applauds the creative efforts made to increase the pool of funding by finding other agencies to cosponsor the work (one agency agreed to do so). However, the lack of any FY 2002 funding from Congress will end this program entirely.

Information Access Division

Technical Merit

The mission of the Information Access Division is to accelerate the development of technologies that allow intuitive, efficient access, manipulation, and exchange of complex information by facilitating the creation of measurement methods and standards. Through collaboration with industry, academia, and government, the division contributes to the advancement of these technologies, enables faster transition into the commercial marketplace, and enables faster transition into applications of division sponsors by coordinating and providing performance metrics, evaluation methodologies, test suites and test data, prototypes and testbeds, workshops, standards, and guidelines.

The Information Access Division is composed of four groups: Speech, Retrieval, Image, and Visualization and Usability. New activities and recent accomplishments in each of these groups are discussed below, together with any potential issues observed by the panel.

The Speech Group continues to work with the Defense Advanced Research Projects Agency (DARPA), the National Security Agency (NSA), and the spoken language research community in industry and at universities to develop metrics for evaluating state-of-the-art speech and speaker recognition systems and to coordinate benchmark tests within the community. The size and scope of the group's efforts have grown in recent years, reflecting the increasing commercial interest in spoken language technologies. New activities in emerging areas include the recognition of conversational speech and its speaker over the telephone and the Effective Affordable Reusable Speech-to-text (EARS) project, which is sponsored by DARPA. The goal of NIST's work on EARS is to develop and carry out performance evaluations of tools to produce transcription of speech that is substantially richer and more accurate than is currently possible. A key step will be in defining the "rich transcription" concept—that is, in defining what features (beyond the text of spoken words) are desired. Another new effort in the Speech Group is that of providing a development and evaluation infrastructure for the pervasive computing's automatic meeting transcription project. This project produces a large corpus of audio and video recordings from meetings, and it is difficult to evaluate this material using current recognition technologies. The Speech Group's work on new evaluation protocols, metrics, and software will make a substantial contribution to the pervasive computing work.

The Retrieval Group is involved in several projects designed to encourage research in and systematic evaluation of information management systems. The best known of these activities is the internationally recognized Text Retrieval Conference (TREC) series. The TREC Program has evolved from its early focus on traditional text retrieval and routing applications to considering much richer information access problems that are of interest to both commercial and government users. Recent focus areas include spoken document retrieval, video retrieval, question answering, and cross-language retrieval, which all continue the TREC tradition of enabling and driving the development of new capabilities. In the effort in video retrieval, which is the newest project in the Retrieval Group, the division's work is pushing the frontiers of multimedia retrieval technologies and developing resources that will provide the foundation for research for years to come. The availability of a testbed for component capabilities (shot detection) and end-to-end tasks (retrieval) will be instrumental in video retrieval research.

In question answering, the focus is on systems that can handle tasks such as returning lists of examples to a single question, interacting with the questioner in a dialog, and knowing when the system does not know the answer to the question. This work is designed to further extend the capabilities of existing systems, and it emphasizes the importance of providing information rather than documents to people. The interest in interactive systems for question answering provides an opportunity for the division's Retrieval Group and its Visualization and Usability Group to collaborate on moving research and evaluation methods forward in the area of interactive systems; the panel looks forward to hearing about progress in this exciting new program.

In the cross-language retrieval area, TREC continues work on strategically important new efforts in Arabic cross-language retrieval. However, some of the other cross-language work has been transferred to other institutions. The European languages have migrated to the Cross Language Evaluation Forum, and the Asian languages have gone to NII-NACSIS Test Collection for IR Systems (both of these organizations are modeled much like TREC). The panel is pleased to see that this transition had occurred, as each organization is now taking the lead on the particular language in which it has the most expertise. Collaborations between the institutions continue, and the most efficient use of resources is occurring.

In addition to the TREC work, the Retrieval Group is also involved in metrics-based evaluation for two other important and challenging areas of information management. The Document Understanding Conference (DUC) focuses on document summarization techniques, which make it easier for people to quickly digest the ever-growing volume of information that they encounter. It is difficult to evaluate summarizing tools, and NIST is contributing to theoretically sound and practically useful assessment methods. Another information management activity is the new Advanced Question and Answering for Intelligence (AQUAINT) Program, sponsored by the Advanced Research and Development Activity. NIST's work in AQUAINT will be on metrics and evaluation tools to drive research and development on techniques for drawing on unstructured and structured data in multiple languages and modalities to find answers to complex questions. This program is not specifically aimed at homeland security applications, but these sorts of techniques could certainly increase analysts' ability to find useful information quickly. The division's role, developing testbeds and evaluating the performance of systems on these more complex tasks, is critical to the overall success of the program.

The DUC and AQUAINT Programs do not yet have the visibility of TREC (in part because DUC and AQUAINT are currently small activities that can only host workshops of a limited size). For these programs to succeed and grow, the division must maintain its focus on the development of test collections and metrics to evaluate new technologies.

The Image Group continues its work on fingerprint databases and testing, as well as on the HumanID project, which deals with multiple and whole-body biometrics used for identification at a distance. The fingerprint work is largely funded by the FBI, and the division's state-of-the-art projects in this group support the FBI's world-leading fingerprint operations. Some of the latest accomplishments include work on standards for palm prints and high-resolution fingerprints, on ways to add demographic information to fingerprint files, and on facilitating the compatibility of U.S. formats with the implementations used by the United Kingdom and Interpol. Last year, the panel noted that the latent fingerprint workstation project in this area had reached maturity, and the division has responded by phasing out this work at NIST and transferring the expertise to an FBI contractor, who is successfully using this product to train fingerprint examiners.

One of the predominant current needs of the law enforcement world is interoperability standards for biometrics used by various government agencies, and the Image Group has a long history of contributing to data format establishment for biometric interchange. The Providing Appropriate Tools Required to Intercept and Obstruct Terrorism (PATRIOT) Act, passed in October 2001, requires NIST to help certify a technology standard to verify the identity of individuals entering the United States. The act specifically mentions fingerprint and face biometrics, in which areas the division has worked for many years, but the identity verification work may also involve human identification at a distance, a field that NIST copioneered just a few years ago. The Image Group's role in responding to the PATRIOT Act is as a database provider and technology evaluator for counterterrorism tools, and the tasks related to this act place a significant burden on the group's resources. Various activities are being planned, including work on certification procedures based on face verification tests previously done by this group for biometrics; the compilation of data sets, including NIST standard databases, DARPA HumanID databases, and other data supplied by government agencies; and the designing of test systems to evaluate performance in various scenarios. These efforts are important, and results are required within 1 year. The group is well positioned to achieve the objectives, owing to the fact that necessary tools, expertise, testing procedures, and databases are in place from its previous work in these areas. As of February 2002, plans for the necessary projects had been formulated and work had begun.

Another ongoing activity in the Image Group is the work on MPEG-7 standards for video and multimedia. Currently only one staff member is assigned to this project; his responsibilities include chairing relevant ISO/IEC committees, developing large MPEG databases and software tools, and hosting the Web sites to disseminate these products. New MPEG standards are currently being determined by the community, and an increase in the number of staff on this project might be needed to ensure that the new standards are technically appropriate.

The Visualization and Usability Group is involved in several efforts aimed at improving the usability of IT software and Web sites. Such improvements in usability can have a significant impact, since poor usability contributes to the high cost of ownership of software, and poor Web site usability results in misinformation, lowered efficiency, and lost opportunities. The Industry Usability Reporting effort and the Common Industry Format (CIF) for reporting cumulative user test results provide the infrastructure for facilitating the sharing of usability information between consumers and producers of software. NIST was instrumental in bringing together industry leaders in several working groups and in driving the effort to fast-track the new CIF standard, which lays the foundation for factoring usability in to software procurement decisions. The CIF test, evaluation, and report (CIFter) project will use the CIF standard to identify efficient and effective usability practices and to develop a benchmark against which new evaluation techniques can be compared. In related work, the Visualization and Usability Group is also involved in developing prototype software and coordinating working groups focused on remote and automated usability testing for Web sites.

Staff from several Information Access Division groups contribute to the ITL-wide effort on pervasive computing. The Pervasive Computing Program began 3 years ago, and NIST has now reached the point at which it can contribute substantially to this nascent field. Two important milestones were achieved in the past year. The first is the completion of a room for automatic meeting transcription in which SmartFlow software collects data from different multimedia input devices, and the second is the development of a general-purpose application programming interface (API) to run these devices.

Over the past 3 years, the panel has offered a series of recommendations on the pervasive computing efforts, mainly concerned with the balance between the creation of novel components and the development of a testbed that could be used to drive research in this field. The panel is very pleased with ITL's responsiveness to its observations, and it notes that the program has progressed to be exactly in conformance with the ITL and NIST missions. Now that ITL has completed the basic infrastructure and testing tools for pervasive computing research, it will be interesting to monitor the progress that the community makes in this field.

Program Relevance and Effectiveness

The ability to quickly and accurately analyze the ever-increasing amount of information that we all encounter is critical to individual and corporate productivity and to government effectiveness. In all of the Information Access Division's groups, work is under way to provide developers and users of information management systems with the tools they need to measure and improve the performance of these systems.

In the Speech Group, NIST-administered benchmark tests have clearly contributed to the improvements in the capabilities of commercial automatic speech recognition products over the years. As the panel observed last year, the division's tests provide a quantitative measure of performance (i.e., the accuracy) of speech recognition systems, and this measure enables technique developers to compare methods and efficiently make advances that will enhance product capabilities.

In the Retrieval Group, the TREC Program takes full advantage of NIST's unique position as an impartial facilitator and evaluator of work to drive research and development of new information retrieval technologies. External involvement in TREC continues to grow; attendance was up 25 percent in 2001, and 35 percent of the participating groups were from industry. Commercial products often utilize ideas and systems first developed in the context of TREC. The program's success is due in part to its continuing evolution; it continually concludes work on tracks where the impact of NIST's benchmarks are diminishing and starts up new programs in emerging areas, such as cross-language retrieval, multimedia retrieval, and question answering.

The impact of TREC can be seen in various ways. The first is the interactions between participants that occur at the annual workshops, where university, industry, and government groups are all in attendance. One of TREC's critical functions is to drive commercial development in areas where government has information management challenges, and past and current programs (such as spoken document retrieval, topic detection and tracking, and multilingual question answering) have demonstrated NIST's success at this task. Another key outcome of TREC is the use of the databases and relevance assessments in a great deal of ongoing experimental work. For example, more than 50 percent of the papers at the most recent ACM Special Interest Group for Information Retrieval Conference used data from TREC to evaluate their systems.

Last year, the division and the panel were questioned by NIST management as to the ongoing relevance of the TREC Program, which began in the early 1990s. The panel examined the current activities in TREC, as it does each year, and in the 2001 assessment report carefully spelled out how TREC has evolved significantly over time and how it continues to provide critical databases, evaluation software, and metrics for industrial, academic, and government institutions to use in developing new information management technologies. In light of this reassurance that TREC continues to provide new and necessary tools to NIST's customers, NIST management has ceased pressuring the division on this question. The panel commends NIST for its responsiveness and its trust in the peer assessment process.

In the Image Group, the work required by the PATRIOT Act on developing and certifying a technology standard for identity verification will certainly have an impact on governmental use of biometric technologies. The homeland security applications of this work bring opportunities and new challenges. First, they give the division a chance to affect agencies outside its traditional law-enforcement-community customers, as these technologies may be used for border security, for identification cards for airport employees, and for drivers' licenses. However, these very applications make the profile of the work much higher than the division is accustomed to, and they bring the NIST activities under scrutiny from technical, political, and privacy groups.

While the increased work on biometrics may have security and governmental origins, it is critical that the division not lose sight of the opportunity provided to influence the commercial human identity technology arena. The biometric industry will benefit immensely from the establishment of proper testing and measurement procedures, which can drive the development of reliable products and increase the industry's credibility with potential users.

Usability is an important and often-neglected component of software and Web site design, and the Visualization and Usability Group has been instrumental in drawing attention to this issue and in providing the tools necessary to improve the situation. The CIF and CIFter Programs are focal points that bring together creators and consumers of information technologies. The CIF Program focuses on working with industry groups to identify techniques for effectively incorporating usability into software procurement decisions. The new CIF standard[10] provides a foundation for exchanging usability information and is already being used for procurement decisions by large enterprises. The CIFter and Web Metrics efforts are focused on improving the methods employed for evaluating the usability of IT products and Web sites.

The results of the Visualization and Usability Group's work are disseminated in a variety of ways. Staff are active in efforts on usability standards at the American National Standards Institute/National Committee for Information Technology Standards and the World Wide Web Consortium (W3C) and in usability conferences, such as the annual Conference on Human Factors and the Web and the ACM Conference on Human Factors in Computer Systems. NIST also sponsors workshops, staff participate in working groups, and the division collaborates with government customers (such as the National Cancer Institute). These activities all make important contributions to improving usability methods and practices in the field.

The division's recent completion of a room for automatic meeting data collection and perfecting of an API for pervasive computing devices will enable staff to produce important tools for the pervasive computing research community. One output is a collection of multimedia databases of meetings produced by the automatic meeting transcription project. These databases are huge (60 GB of data for each hour of meeting time) and would be difficult for any individual research group to compile on its own. NIST's compilation and dissemination of these databases will facilitate research and improve the state of the art by enabling comparison testing of various products and techniques. The second key division product is the API itself. The API, which came out of Smart Flow data capture work, is a critical tool for efficiently setting up multimedia and pervasive computing laboratories. This API will allow researchers to connect cameras and microphones and other equipment without building their own baseline software each time. Thus, researchers can focus directly on experiments in their laboratories, and comparative testing on a common platform will now be possible. NIST's work in pervasive computing is appropriate, and its results are of great interest to the relevant research community. A workshop hosted by NIST in May 2001 attracted representatives from groups from around the world.

The Information Access Division effectively disseminates its results to a wide variety of customers. Eight workshops and conferences were organized by division staff in 2001, and these meetings were attended by representatives of many respected academic and industrial organizations. In addition, the proceedings from these conferences are often published by NIST and made publicly available on the

[10]This is American National Standards Institute National Committee for Information Technology Standards (ANSI/NCITS) 354-2001.

Internet. Test sets, databases, and APIs produced by the division are frequently downloaded from the Web, and these packages, related to biometrics, speech, information retrieval, and usability, have been circulated widely. Division staff also give presentations, participate on standards committees, and publish papers in journals, conference proceedings, and other publications. Roughly one-fifth of the division's 27 publications in 2001 appeared in archival journals; the panel encourages staff to explore whether more papers could appear in these sorts of journals, to supplement the publications in conference proceedings, which may be less widely available to potential NIST customers.

Division Resources

Funding sources for the Information Access Division are shown in Table 8.5. As of January 2002, staffing for the division included 40 full-time permanent positions, of which 35 were for technical professionals. There were also 6 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The level of resources has been adequate for most projects in the Information Access Division. A very high percentage of the division's funding comes from outside sources—currently support is provided by several agencies, including DARPA, AROA, the FBI, NSA, and the National Institute of Justice. In the past, the panel has expressed concerns about the relative balance between internal and external support, but it does recognize that division management is aware of the potential risks associated with dependence on outside funding. The panel also believes that the ongoing work for other agencies is appropriate for the division and that it serves to advance the NIST mission, particularly as homeland security is one of NIST's new Strategic Focus Areas.

The growing emphasis on activities related to homeland security and the new burdens imposed by the PATRIOT Act may strain the current resources allocated to this division. If new staff time and funding are needed to meet the goals in these areas, the panel hopes that resources can be provided from new allotments of congressional funding and from other government agencies rather than from reallocation. ITL and division management should be wary of the impact of these programs on other division

TABLE 8.5 Sources of Funding for the Information Access Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	4.5	4.6	4.8	4.6
Competence	0.0	0.0	0.0	0.1
ATP	0.2	0.1	0.0	0.0
OA/NFG/CRADA	3.2	4.0	4.5	4.4
Total	7.9	8.7	9.3	9.1
Full-time permanent staff (total)[a]	40	39	39[a]	40

NOTE: Sources of funding are as described in the note accompanying Table 8.1.

[a]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

activities, whose progress could be delayed or curtailed as a result of pressure from the homeland security work.

The human resources available to the Information Access Division are quite good. The division gains access to fine and relatively inexpensive researchers by offering temporary positions to European students and postdoctoral research associates. Unfortunately, the division is seldom able to hire even the best temporary employees to permanent positions, as slots seldom open up. However, the low turnover among the permanent staff does testify to the high morale and good working environment that clearly exist in this division.

Convergent Information Systems Division

Technical Merit

The mission of the Convergent Information Systems Division is to conduct research and development into integrated systems, architectures, applications, and infrastructure for the exchange, storage, and manifestation of digital content and to explore their scalability, feasibility, and realization for new applications.

In line with its mission statement, the Convergent Information Systems Division continues to provide industry with important standardization and testing services for the exchange, storage, and manifestation of digital content. The projects under way examine technologies and investigate the issues that arise when combining these technologies. Division staff then focus on producing tools and knowledge to facilitate pulling complete systems together.

The Convergent Information Systems Division was formed in October 2000. During 2001, its first full year of operation, the division won numerous prestigious awards, and the panel commends the division for the ongoing evolution of its projects—through shifts in focus within broader program areas, through starting up entirely new activities, and through the conclusion of completed projects. The division has two organizational units, the Distributed Systems Technologies Group and the Information Storage and Integrated Systems Group, and work during 2001 occurred in approximately seven program areas. Below the panel discusses objectives, highlights, and issues in six of these ongoing programs: Digital Cinema, Biometrics, Optical Disk Storage, Trust Management/Digital Rights Management, E-Books and the Braille Reader, and Interactive Digital Television. Work in the seventh area, Cluster Computing, is concluding this year.

In the Digital Cinema Program, the focus is currently on content manifestation and consumption. The division has set up a facility that industry groups and vendors can use to test parts of the digital cinema chain. The goal is to provide industry with test and measurement services for digital cinema acquisition devices, transmission facilities, storage devices, and display systems. One recent accomplishment is the development of a computer application that can preview how compressed MPEG video appears on displays with various color bit depth; such an application can allow a producer or editor to make decisions about the amount of compression in light of the equipment likely to be used by the target audience. Another activity is the establishment of a multimedia editing system that takes input from a variety of sources, allows audio and video editing, and can output the results in any digital or analog format. This system allows division staff to research digital content types on a low-cost, PC-based editing system and provides broad flexibility in achieving the goals of content interoperability. Using this system, the division is testing the interoperability of different digital content types, developing tools for interoperability use, and studying performance issues related to content transfer and delivery (e.g., download times for enhanced content). The system will also enable staff to examine the usage of recombinant media types, such as mixed video, text, and audio, for specific digital applications (e.g., electronic learning) or for content compatibility with writable storage media (e.g. DVD/CD R, RW).

The division continues its long-standing work in biometrics. This past year, the division facilitated the creation of two critical standards for biometric technologies: the Biometric Application Programming Interface (BioAPI, version 1.0) and the Common Biometric Exchange File Format (CBEFF). BioAPI provides a common program interface for biometric devices and was approved as an ANSI standard in February 2002. This interface enables programmers to write code that can be used with multiple capture devices or with back-end minutia extraction routines. The BioAPI specification technology is critical in allowing biometric devices to have a common look and feel. The CBEFF, which was published in January 2001,[11] provides a standard biometric data format that facilitates data interchange across different applications and devices. Currently, the International Biometric Industry Association is managing the registration of CBEFF format owner and format type values. The division's work has been critical to the success and growth of the biometrics industry. The panel notes that there are several ways in which NIST could continue to assist the biometrics research and development community in improving its products. Particularly helpful would be standardized mechanisms for determining false acceptance and false rejection rates, for evaluating and classifying various recognition algorithms and software, and for defining standard threat and usage models to enable effective definition and evaluation of implementation and deployment requirements.

Another long-standing effort is the work in the Optical Disk Storage Program, which includes a number of individual projects. A facility has been built in which the lifetime of data stored on digital versatile disks (DVDs) can be tested. Also, staff have developed an application software package to test the compliance of DVDs and compact disks (CDs) with the CD-Multi standard. This package is the only software available to companies and consumers for checking whether their drives are compatible with the disks on the market. Future activities in the Optical Disk Storage Program include the construction of a laboratory to test interoperability for optical jukebox storage units. No interoperability among the various storage systems currently exists, and the division hopes to use this new facility to help the industry develop interoperability tools. The laboratory will be a joint project with the High Density Storage Association (HDSA), and a CRADA has been put in place between the division and HDSA. All of these projects contribute to the division's ability to take an active role in the DVD community. With the DVD Association, the division is cosponsoring a June 2002 conference on DVD standards, technologies, applications, and use for homeland defense.

The Trust Management Program is continuing its evolution toward a focus on digital rights management (DRM) and content encapsulation. Work continues on financial agent secure transactions (FAST); industry recently endorsed the division's efforts to examine the relevance of this trust model to e-commerce exchange by small electronic manufacturers. In DRM, the division has hosted two workshops to bring together the providers of content (such as movies, music, and books) that requires digital content protection with the makers and proponents of various technologies whose purpose is to supply this protection. The panel believes that these workshops should be an opportunity for NIST to obtain commitment from various industry content providers and technology providers to cooperate in the creation and use of a truly interchangeable format. If these stakeholders agree to this goal and if they require NIST's assistance in the standardization of rights management for digital content, then the

[11]Fernando L. Podio, et al., U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Common Biometric Exchange File Format*, NISTIR 6529, National Institute of Standards and Technology, Gaithersburg, Md., January 2001. Available online at <http://www.itl.nist.gov/div895/isis/cbeff/CBEFF010301web.PDF>.

Convergent Information Systems Division should build a more substantial program in this area. Since the division does not currently participate in DRM activities, it may be particularly suited to bring consensus among the participants in this contentious area.

The division's work on electronic books (e-books) brought together diverse groups from the industries interested in electronic publishing. However, in the end these stakeholders did not agree to develop and use truly interoperable hardware formats that would allow books in various content formats to be read using software from different vendors. The division has managed to create a common format within which various proprietary book formats may be placed for easier exchange across platforms. Given the industry's unwillingness to truly embrace interoperability, the panel believes that this program either should be concluded or should be redirected toward work in the broader area of electronic publishing, encompassing issues related to hardware interoperability, assistive technologies, and sources of content capture (e.g., digital cameras). Such activities would complement the division's new focus on content packaging and formatting and content manifestation and consumption (the DRM work). The goal would still be achieving true interoperability between book formats and reader software in the market. However, continuation and redirection of this program should only occur if the market for electronic books appears to pick up, with the development of new hardware and the making of new commitments by publishers.

The division's work on digital television (DTV) is winding down. NIST has provided a significant service to industry by releasing the first public and free implementation of the Java APIs, which are used as the Advanced Television Systems Committee's (ATSC's) interactive DTV middleware standard. However, the broadcast market for interactive DTV is not taking off as many had expected. The panel therefore supports the division's decision to redirect resources in new directions, such as middleware for biometric systems. The expertise gained in middleware development from the DTV application software environment (DASE) project will be crucial for examining the issues related to the integration of biometric point solutions into robust system architectures. For example, the deployment of biometric systems for homeland security will require that the middleware environment be tested for performance and that standard system evaluation methods be developed.

Overall, the panel commends the willingness of the Convergent Information Systems Division to refocus and to conclude programs. The division has been responsive to recommendations made in last year's assessment, as can be seen in the conclusion of some projects (such as time synchronization, DASE, and the Braille Reader) and the increased emphasis on others (such as biometrics and data preservation). New activities, such as the work on rights management for digital content, have been built on existing programs, and entirely new projects have been started, such as the quantum information testbed. In this last activity, the Convergent Information Systems Division has taken over supervision of the facility, which is a joint project between ITL and the Physics Laboratory. The facility is supported by DARPA, which toured the facility in February 2002 and is pleased with the progress being made on this work.

Program Relevance and Effectiveness

The Convergent Information Systems Division reaches out to a diverse group of customers through various mechanisms. The staff make information about the division's results, products, and activities available through publications and through the recently overhauled divisional Web site. Presentations are given to fellow researchers at conferences, to industry representatives at workshops, and to the public at schools and science fairs. The staff collaborate with researchers in other units and at other institutions; there are eight ongoing collaborations with personnel in other ITL divisions or other NIST laboratories and four collaborations with university researchers. The division also regularly gives tours of its facilities and has filed for patents (one in 2001) when necessary. The division gathers a variety of data on all of these dissemination efforts, and the panel suggests that the metrics used could be further refined. For example, in the area of Web hits, appropriate additional questions might include who downloaded what, how and why they used it, and what benefits were realized.

The diverse array of outreach activities enables the division to connect with customers in its three main audiences: the government, industry, and the public. Although the division's primary focus is on industry, several of its projects are particularly relevant to other government agencies in light of the events of September 11. NIST's work on defining biometric standards will be heavily leveraged as the country looks at deploying mechanisms to identify terrorists and track terrorist activity. The division brings particular expertise with respect to the systems-level issues for using biometrics, and it has two relevant and newly funded projects—Biometrics Systems Integration and Efficient Infrastructures for Biometrics. The Convergent Information Systems Division's efforts in this area will complement the work under way in the Information Access Division, which has been tasked under the recent PATRIOT Act with evaluating biometric technology for border and visa control. Even prior to the emphasis on homeland security, the Convergent Information Systems Division's biometrics programs were relevant to various government customers, and division results are being utilized already in the Department of Defense's Biometric Management Office and the General Services Administration's Common ID card project.

Another division effort with potential homeland security applications is the work on data preservation in the optical disk storage area. The division's standards and tests for determining the lifetime of data stored on various disks and for quantifying the influence of environmental factors on disk performance will provide crucial information for determining strategies and systems for disaster mitigation and recovery efforts. Relevant current projects include the development of codes for data recovery from optical disks and the construction of the NIST-HDSA interoperability test facility. As with the biometrics projects, the Optical Disk Storage Program also has governmental customers outside homeland security applications. Division staff currently serve on the Advisory Board for the Library of Congress. This board has been tasked by Congress to develop a national strategy for data preservation of digital content, which is a $175 million effort. As a result of inputs by NIST, the National Science Foundation and the Library of Congress sponsored a workshop in April 2002 on developing a national agenda for data preservation. The workshop assembled experts from around the country, from academia, government, and industry. The division headed the session on data preservation tools and technology.

The Convergent Information Systems Division has a close and productive relationship with companies in a variety of industries. The main form of interaction is through industry and professional associations. For example, NIST leads the Biometric Interoperability, Performance, and Assurance Working Group of the Biometric Consortium. This group includes 85 organizations and has three key projects: performance test procedures, CBEFF format for smart cards, and biometric assurance requirements. The value of the biometrics work to industry was roughly quantified in a recent economic impact study by Business Process Research Associates, which cites the division's efforts in biometrics as having delivered up to $136 million in benefits through its work to consolidate two competing standards organizations and its facilitation of the adoption of both BioAPI and CBEFF. The value of the division's work to industry is also made clear by testimony from various commercial groups. In the DASE project, the appreciation of the industry was expressed in a letter from the executive director of the Advanced Television Systems Committee. In the Digital Cinema Program, the work on color characterization for display technologies received a warm testimonial from the Society of Motion Picture and Television Engineers. In the trust management area, the Financial Services Technology Consortium (a consortium of banks and lending institutions) is endorsing and using NIST's efforts on FAST.

In all of the division's programs, the ultimate beneficiaries are the users of the various systems made by the division's industrial partners and customers. NIST's standards and tests and interoperability tools all help industry improve its products. In some projects, however, the primary beneficiary of the division's work is the public. The Braille Reader developed by division staff has won two prestigious innovation awards: the R&D 100 Award given by *R&D Magazine* and the Top40 Socially Conscious Innovations Award given by *ID Magazine*. However, industry has not adopted this technology, and no company seems to be looking to deploy or produce a Braille Reader at this time. Therefore, the division is working with the National Federation for the Blind on ways in which the federation might take this assistive technology forward into mainstream production.

Despite the effectiveness of division interactions with governmental and business customers and the benefits that consumers experience from the work done at NIST, an issue still exists with respect to communication to the world at large. For example, the division's work on disk lifetime characterization and on CD and DVD compliance testing needs more exposure and publicity if consumers (individuals and companies) are going to understand the benefits and make use of the information when making purchasing decisions. The multiread standard is used by manufacturers of disks and equipment in the CD and DVD industry, but consumers, if they were aware of the implications of the CD-Multi specification and logo, could use the information to judge compliance of drives and disks. This information is especially useful in light of the upcoming fragmentation of the market in DVD-recordable drives and disks.

Division Resources

Funding sources for the Convergent Information Systems Division are shown in Table 8.6. As of January 2002, staffing for the division included 14 full-time permanent positions, of which 12 were for technical professionals. There were also 18 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

The small number of permanent staff (14) in the division is supplemented by a large cadre of guest researchers (6) and students (12). While this approach has some risks, particularly with regard to the continuity of programs, these temporary employees greatly expand the capabilities available to the division and provide flexibility. When the division had to replace a permanent staff member in 2001, the recruitment and hiring process for this type of position took an inordinate amount of time.

The Convergent Information Systems Division is unusual in ITL in that laboratory experiments are carried out by division staff. Thus, making sure that staff have access to up-to-date equipment is vital to maintaining their credibility as systems engineering experts tackling problems related to current industry needs. For example, the work on biometrics and related access authentication usage and models requires samples of the relevant technology and equipment. The same need exists in the Digital Cinema laboratories. Testbeds for industry products or software must contain the products and software being used in industry.

The division is tightly packed into the space currently allocated for its work. However, the division conducts more than 30 tours a year of its laboratory facilities, and, through a close relationship with the NIST Office of Public and Business Affairs, these laboratories provide ample public relations value to NIST. Thus, any contraction or relocation of divisional facilities would negatively impact staff productivity, their ability to demonstrate cutting-edge technologies to industry and other government agencies, and NIST's promotional efforts.

TABLE 8.6 Sources of Funding for the Convergent Information Systems Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)[a]	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	2.6	2.2	2.3	2.3
STRS—supercomputing	9.9	10.0	0.5	0.0
ATP	0.6	0.8	0.6	0.8
OA/NFG/CRADA	0.4	0.8	0.3	1.0
Other Reimbursable	0.0	0.8	0.0	0.0
Agency Overhead	6.7	7.4	0.0	0.0
Total	20.2	22.0	3.7	4.1
Full-time permanent staff (total)[b]	75	81	13[b]	14

NOTE: Sources of funding are as described in the note accompanying Table 8.1.

[a]The significant difference between the FY 2000 and FY 2001 funding and staff levels reflects the reorganization of the Information Technology Laboratory, in which the information technology service groups and the Scientific Applications and Visualization Group were moved out of this division to the Information Services and Computing Division and the Mathematical and Computational Sciences Division, respectively.

[b]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

Information Services and Computing Division

Technical Merit

The mission of the Information Services and Computing Division is to provide an efficient, effective, and secure NIST IT environment and advance the utilization of IT to empower NIST and its stakeholders to accomplish their mission with maximum impact. The vision of the division is to be a vital partner in the accomplishment of NIST's mission through the provision of premier IT services.

The division's current responsibilities include supporting administrative and scientific computer systems, deploying and maintaining telephone and data networks, and providing high-performance computing capabilities and data storage. These IT service activities were consolidated into one division in October 2000. Since that time, division staff have worked hard to define the role of an IT support unit—what their responsibilities are and how best they might provide those services to the rest of NIST. Using a consultant, the division has developed a blueprint describing an architecture for IT at NIST; this plan should serve NIST well in the future.

In February 2002, the newly appointed NIST director announced that the Information Services and Computing Division would soon be subsumed into a new, institute-wide IT services organization. This organization will be run by a chief information officer (CIO), who will report directly to the director of NIST. The review panel applauds this decision, as the shift is appropriate in light of the increasing strategic importance of computing and communications in the research and administrative functions of NIST.

Despite the fact that the Information Services and Computing Division was created less than 2 years ago and despite the new uncertainties raised by the recently announced plans for another major organizational shift, the division has made significant progress since the previous assessment. The panel is impressed by the energy and seriousness with which the division responded to recommendations in the 2001 assessment report and by the improvements made in a number of areas.

A prime example of the division's responsiveness to the panel's concerns is the work done on getting NIST connected to Internet 2. Last year, the panel had been troubled by the poor connectivity available to NIST researchers. This year, funding has been secured to support NIST's joining an Internet 2 consortium, and a plan is set to get the connection in place by October 2002. The commodity Internet connection will remain in service, as this link will still be required to exchange data with entities not served by Internet 2. The panel applauds this effort, as access to Internet 2 is expected to enhance NIST researchers' ability to collaborate with leading universities. As the division moves forward on this task, a key challenge will be promoting and supporting Internet 2 within NIST. The division should not assume that this higher-performance, wider-area networking capability will be instantly embraced or effectively utilized by research staff. Experiences at universities already connected to Internet 2 suggest that many researchers will not understand either the short-run or longer-run implications of Internet 2, and education and training will be necessary to convince them of the benefits and eventually to produce the expected increases in research productivity.

While rolling out support for Internet 2, the division also might want to explore whether NIST could also get connected to the national high-performance grid. In grid computing, high-performance networks, sophisticated management software, and other middleware enable sharing of remote high-performance computing systems, instrumentation, and data collections. This approach could be a useful way to provide better, more efficient high-performance computing to NIST researchers in the future. At the present time, however, the panel is pleased to note that the division has upgraded the existing high-performance computing platforms.

A variety of important advances occurred in the past year in the array of services that the Information Services and Computing Division provides NIST. One of the most noticeable and exciting changes was the creation of a central IT help desk. Facilities were constructed in Gaithersburg and Boulder, and the service was officially launched in February 2002. The scope of the help to be offered is broad; people's questions on PC support, Web services, scientific computing, computer security, networking, telecommunications, administrative applications, and Unix and NT servers will all be directed to the help desk staff. The comprehensive nature of this centralized service is important, as the goals of creating it include reducing customer confusion about what services the division provides and about who can help them. Another potential benefit will be a uniform system for tracking service requests and generating service performance metrics.

An important responsibility of the Information Services and Computing Division is related to the security of NIST's computer systems. Progress has occurred in this area in the past year, but issues still remain. Steps forward include the deployment of an E-Approval system, which prepares NIST to comply with the Government Paperwork Elimination Act that goes into effect in 2003. The system is based on a NIST-wide public-key infrastructure, which also supports digital signatures and e-mail encryption.

The panel believes that it is important for the division to push forward with its plans to upgrade network and systems security at NIST. A major current concern is systems administration, which is distributed to people throughout NIST and is acknowledged by staff to be out of control. For example, no way currently exists to comply with the Department of Commerce directive to terminate staff accounts within 24 hours of separation. Larger audit requirements are also not being met.

Another area of potential improvement is that of business continuity planning. While a disaster recovery approach is in place with a contractor (Sungard), the panel believes that the plan could be updated. The current plan does not appear to reflect or accommodate the increasingly computer- and data-intensive research and administrative work performed at NIST. Also, the plan should take full advantage of the fact that NIST has two physical campuses (Gaithersburg and Boulder), and the option of using distributed data centers at these sites should be considered.

Program Relevance and Effectiveness

The Information Services and Computing Division serves customers throughout NIST, and NIST could not function efficiently or turn out the high-quality research discussed throughout this report without the support of this unit. Not only do the division staff maintain the telephone and networking infrastructure and support the 9,100 desktop PCs at NIST,[12] but they also provide needed capabilities to individual units, such as administrative applications (e.g., for accounting) and high-performance computing capabilities (e.g., for scientific modeling programs).

The division has made a number of efforts this year aimed at saving time and money for NIST staff in their IT activities. One example is the launching of a NIST-wide PC-buying service, which will be extended to Unix workstations later this year. Centralized purchasing of PCs (and workstations) will produce several benefits both for the division and for NIST staff as a whole. Some of the pluses are reduced administrative and procurement costs, uniform security setups on all new PCs, and easier installation of new technologies and software. For example, by having IT services staff determine standard configurations of PCs and workstations that are compatible with NIST's security and administrative requirements and having these staff manage the migration and installation of the new systems, NIST researchers will save time previously devoted to researching systems and transferring their work.

The division is focused completely on serving the needs of its customers—NIST personnel—which is appropriate. However, the panel believes that the division might benefit from reaching out to other organizations that support active IT-intensive research. Many research universities, other national laboratories, and corporate research and development entities face challenges similar to those at NIST: diverse platforms and widely varying technical expertise in their user communities. Relationships with these organizations might provide information about best practices, alternative solutions, and lessons learned that the division could productively apply to IT services at NIST. One possible way to engage with these institutions would be through memberships in relevant associations, such as Educause, the premier IT management association serving higher education and related entities, and the Global Grid Forum, a large collection of individual researchers and practitioners working on distributed computing, or grid technologies.

Division Resources

The panel believes that for the Information Services and Computing Division to move forward with many of its plans for improving the IT environment at NIST, it must proactively engage the NIST research community. While the division is the primary source of IT expertise and support, some of the responsibilities for IT services are dispersed throughout NIST, as is the case in many research universities. This situation has positive and negative aspects. The negative aspects include the costs, in both

[12]The total number of desktop computers breaks down approximately as follows: PCs, 7,500; Suns, 600; SGIs, 200; and Macs, 800.

money and efficiency, of inconsistent or duplicative efforts—for example, the distributed systems administration, which is weakening computer security at NIST. Another example is contracts with external providers of services or software, where each individual unit negotiates its own rates and terms. The panel is pleased to see that the division is working very hard to fix both of these situations. The positive aspect of IT services being provided in the units is the presence of support staff who work closely with a specific set of researchers and understand deeply and well their needs and constraints.

To take full advantage of the positive aspects of dispersed IT support personnel, the panel suggests that the division consider creating numerous separate, and perhaps unique, service-level agreements with the laboratories and research groups rather than a uniform approach to diverse NIST-wide needs. A range of agreements might reassure the laboratory staff that the division recognizes that each group has its own special needs, and then it might make the researchers more understanding of the instances in which some degree of uniformity is necessary (e.g., in security). Another path to encouraging conformance to standards and use of centralized services is that of making the centralized services more attractive than the alternatives. When the central mail services were improved recently, more people began using the main mail servers, and many of the small independent, unsupervised mail servers in the individual laboratories were able to be shut down. Security improved, and the amount of time spent NIST-wide on supporting e-mail services decreased. The recent launch of a centralized PC-buying service is another example of providing incentives for researchers to embrace a more efficient and uniform system. In the future, the division might consider consolidating server and storage functions so as to both improve responsiveness to the laboratories' research agendas and reduce NIST's overall costs and risks of lost data.

The panel is pleased to learn that the new IT services unit will include a group focusing particularly on providing solutions to assist researchers in tackling unique scientific problems. The goal would be to help NIST staff in the laboratories utilize commercial off-the-shelf products relevant to their experiments and perhaps to create an "explorers group" that would investigate new software and hardware that might be applicable to NIST research. The panel supports this approach and hopes that it will help the IT support group engage the NIST research community in creative thinking about IT solutions and allow the scientists to realize the value that IT can add to their experimental work. It was not clear to the panel if the current structure through which the division receives advisory input from the laboratories is actually providing (or being perceived as providing) optimal opportunities for two-way communication. It is also possible that communications and relations between the IT services unit and its customers might improve with the increased stature of IT services that may result from its organizational shift from laboratory division to individual unit whose head reports directly to the NIST director.

The panel notes that one consequence of the organizational change will be that the IT services are no longer reviewed by the National Research Council assessment panels, which review the programs under way in the NIST Measurement and Standards Laboratories, such as ITL. External assessments of programs drive self-evaluation as well as providing unbiased advice from different perspectives, and the panel recommends that NIST management explore ways for the new unit to receive this sort of input from outside the institution.

Funding sources for the Information Services and Computing Division are shown in Table 8.7. As of January 2002, staffing for the division included 136 full-time permanent positions, of which 109 were for technical professionals. There were also 11 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

In last year's report, the panel encouraged division and laboratory management to look for ways to increase diversity at the management level. This year, as part of a reorganization of the division's groups, competitions for several top-level positions were reopened in search of candidates, to bring new

TABLE 8.7 Sources of Funding for the Information Services and Computing Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)[a]	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	0.6	0.9	0.3	0.2
STRS—supercomputing	0.9	0.9	7.4	9.1
ATP	0.0	0.0	0.1	0.2
OA/NFG/CRADA	0.0	0.0	0.6	0.7
Other Reimbursable	0.4	0.6	1.0	0.3
Agency Overhead	7.1	8.2	18.2	25.8
Total	9.0	10.6	27.6	36.3
Full-time permanent staff (total)[b]	72	77	131[b]	136

NOTE: Sources of funding are as described in the note accompanying Table 8.1.
[a]The significant difference between the FY 2000 and FY 2001 funding and staff levels reflects the reorganization of ITL, in which information technology service groups were moved out of the Convergent Information Systems Division and into this division.
[b]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

people into the management ranks. Although few women and minority management candidates were ultimately identified, the initiative set an important precedent, and the panel supports further efforts in this area.

Software Diagnostics and Conformance Testing Division

Technical Merit

The mission of the Software Diagnostics and Conformance Testing Division is to develop software testing tools and methods that improve quality, conformance to standards, and correctness; to participate with industry in the development of forward-looking standards; and to lead efforts for conformance testing, even at the early development stage of standards.

The division's work designing conformance and diagnostic tests and developing reference implementations for standards bodies clearly fulfills its mission and is consistent with the goals expressed in both the division and NIST missions. The division is organized in three groups: Software Quality, Interoperability, and Standards and Conformance Testing. The technical merit of the work of all three groups is quite high.

The Software Quality Group develops methods to automate software testing, develops software diagnostic tools, and performs research in formal methods. Projects under way include work on automatic test generation, enterprise single sign-on, quantum information, interactive television, and health care information systems. In the automated test generation project, staff have drawn upon prior work in test harnesses, mutation testing, and specification-based testing. This project is relatively mature, and the panel expects that the current toolset will be transitioned to industry quite soon. The staff have maintained an excellent relationship with Ford Motor Company over the course of this project, and the division should consider Ford and other companies as possible targets for this technology transfer.

If the automated test generation project does continue at NIST, the division might consider adding formal test oracles to the toolset; these could be used for checking test results against specifications of expected and/or desired functionality or other quality properties. In the current toolset, the test data are generated on the basis of specification mutations that are used to provide an adequate range of tests for the software. According to the mutation testing paradigm, a mutation "test" is killed if it provides different results from the original test, but the original test's "correctness" is determined by some other means. This approach is extremely costly and, if not automated, potentially error-prone. Using the formal specifications to develop automated test oracles would be an effective alternative. Since formal specifications are available in the domains of exploration (consortia and standards bodies), the use of formal specification-based test oracles would improve the quality of the toolset at a limited additional cost.

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 Council, in the application of standards and the development of interoperability tests for IT systems and products that cross several agencies. Current projects include the National Software Reference Library, computer forensics tool testing, and work on metadata standards. Group staff also serve as ITL representatives on a variety of standards committees.

The Standards and Conformance Testing Group develops conformance tests and reference implementations, performs research into better ways to do conformance testing, and, working with industry, develops standards for emerging technologies. Currently, the primary focus areas of this group are XML and pervasive computing. In the XML area, the panel continues to be impressed with how well the division works with industry groups to establish means by which software and systems can interoperate over the Internet. In pervasive computing, a key component of the work is related to architectural description languages (ADLs), which can improve technical specifications of system architectures, especially for those systems in which dynamic adaptation and dependability are required. The panel commends the division's decision to focus pervasive computing efforts on ADLs and simulation; elements of this project will be relevant to applications well beyond the context of pervasive computing.

The panel has two suggestions about the ADL efforts. One is to consider whether xADL might be relevant to the project. Unlike traditional ADLs, xADL has an emphasis on dynamically reconfigurable architectures and is defined as a set of XML schemas. This approach gives xADL extensibility and flexibility, as well as allowing basic support by many commercial XML tools. The panel's second suggestion is to consider expanding the intent of the ADL effort beyond improving and extending specifications and to include work on specification-based testing activities. A substantial amount of current work exists in the area of architecture-based testing, where the ideas behind specification-based testing are applied on the basis of formal architecture descriptions. Architecture-based testing is particularly useful in integration, conformance, and interoperability testing, because it is tied to the architectural design level. It is applicable in analysis, test planning, and test generation at the stage of specifying the architectural configuration and then equally applicable in actually testing the software during integration. This approach would complement and support several other division projects and hence seems worth exploring.

Program Relevance and Effectiveness

The Software Diagnostics and Conformance Testing Division delivers value to users and providers of software through its facilitation of 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 advancements 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 this division, provides government and industry with a service that is both necessary and unique.

The panel continues to be impressed by the division's focus on emerging technologies and the effectiveness with which it partners closely with industry. Staff work well with a wide variety of organizations (e.g., the Organization for the Advancement of Structural Information Systems [OASIS], the Worldwide Web Consortium [W3C], the Air Transport Association [ATA]), and the division also works directly with individual companies, such as Ford Motor Company, Sun Microsystems, IBM, and Microsoft, on products and applications to improve the interoperability available to users. Overall, the division's relationships with industry and industry groups are outstanding. The panel does note that the division's focus on these important activities has limited the time and effort available for publications and presentations in what academics would consider the top-tier journals (e.g., IEEE or ACM transactions) and conferences (e.g., the International Conference on Software Engineering, the International Symposium on the Foundations of Software Engineering, and the International Symposium on Software Testing and Analysis). However, through its more general projects, the division does support various research communities. For example, the ADL work provides a common set of measurements to enable comparison and analysis across systems, and this clearly fulfills an important need of the ADL community.

The federal government clearly benefits, as do all users, from the division's work to improve the interoperability and performance of commercial software systems. However, the division also has a range of activities targeted directly at assisting a variety of agencies. The highest-profile projects are the National Software Reference Library and the computer forensics tool testing, which serve the law enforcement community at many levels. The work with the Federal CIO Council also continues to be important across government, and various projects are supporting individual agencies. For example, the work on health care information systems is being done in conjunction with the Department of Veterans Affairs.

The division's effectiveness is exemplified by the XML conformance project. In this effort, the division's significant contributions to the standards process were critical to the success of XML as a truly "open" standard. While industry itself recognized the value of conformance tests, it was unwilling or unable to commit the resources needed to organize the development of a substantial set of tests for XML. A fledgling effort was established by an industry consortium to undertake this effort, but it failed to generate sufficient support. The division stepped into the partial vacuum created, led a revitalized effort, organized support by industry, and collected tests from a variety of sources. These actions facilitated the open discussion of conformance to the standard by major (and minor) suppliers of XML technology, and the division is primarily responsible for the overall success of the effort and the existence of the standard and the conformance tests that are necessary to allow the use of XML to flourish. W3C has now initiated a quality-assurance activity in this area, and the panel hopes that the division's experience and expertise will be effectively utilized as industry moves forward on defining XML standards, testing, and usage.

As can be seen in the example above, a key element of NIST's effectiveness is the division's good relationships with industry and its ability to work with industry groups such as consortia. Timing is a critical factor, too, as the division's impact on standards and software is dependent on getting involved early in the standards development process. However, to participate effectively in consortia often requires legal paperwork and agreements, and the division continues to be hindered by the poor responsiveness of the Department of Commerce legal department.

The panel is particularly impressed with the division's record both on beginning and concluding projects. Division staff have shown good judgment in selecting new areas in which to work, which is particularly impressive given the wide range of standards activities on which this division could potentially have an impact. The division's philosophy of getting involved early in the standards process (focusing on emerging technologies) and partnering with industry maximizes the value of NIST's work. In addition, the division has shown a willingness to discontinue work in an area if NIST's contributions do not appear to be needed or if the technology is not being embraced as anticipated. Finally, the division is good at setting metrics and goals at the beginning of each project so that it will be clear when the objectives have been accomplished and it is time to conclude the project. This year, the Role-Based Access Control project and the Computer Graphics Metafile (CGM) project have been concluded, and the resources largely allocated to other projects. However, NIST staff will continue to support work in these areas when there is a specific industry request for their assistance. This willingness to provide ongoing support when necessary requires very little actual time from NIST staff but is important for ensuring successful technology transfer.

Division Resources

Funding sources for the Software Diagnostics and Conformance Testing Division are shown in Table 8.8. As of January 2002, staffing for the division included 37 full-time permanent positions, of which 33 were for technical professionals. There were also 15 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

TABLE 8.8 Sources of Funding for the Software Diagnostics and Conformance Testing Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	4.8	4.8	4.9	5.3
Competence	0.6	0.5	0.5	0.4
ATP	0.4	0.6	0.2	0.0
OA/NFG/CRADA	0.6	1.0	1.9	2.8
Total	6.4	6.9	7.5	8.5
Full-time permanent staff (total)[a]	39	37	35[a]	37

NOTE: Sources of funding are as described in the note accompanying Table 8.1.

[a]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

The panel continues to be impressed by the high degree of camaraderie exhibited between and among managers and staff in this division. Various factors appear to contribute to the good morale observed. One is the strong sense of teamwork that exists; communication within the division is very good, and since there are no one-person projects, staff do not feel isolated. In addition, a very high percentage of the division's activities involve collaborations with other ITL divisions, and these relationships expand division staff's knowledge of various technical fields and are good for morale. The division has successfully recruited several new staff members in the past year, and the panel considers that the division is quite healthy. Only two concerns were expressed by staff in informal interactions with the panel. One is the difficulties experienced in dealing with the NIST procurement system; the delays in purchasing equipment are particularly frustrating in the IT arena, as the technology available changes rapidly and the division requires access to relevant hardware and software to have an impact on industry. The second concern was the division's budget deficit as of February 2002; it was not clear where the funds necessary to make up this gap would come from.

Statistical Engineering Division

Technical Merit

The mission of the Statistical Engineering Division is to advance measurement science and technology by collaborating on NIST multidisciplinary research, by formulating and developing statistical methodology for metrology, and by applying statistical principles and methodology to the collection and analysis of data critical to NIST scientists and engineers.

The division is involved in a broad range of activities, including the provision of support to NIST scientific research, collaborative multidisciplinary research with NIST scientists, development of new statistical methodology with a special focus on metrology, and the transfer of statistical methodology to NIST scientists and the broader scientific community. The demand for collaborative interactions with division staff continues to be very high. Less than 2 years ago, a new division chief was hired; her primary task has been to rebuild the Statistical Engineering Division into a premier national resource for statistical sciences. Great progress has been made on this task, and continuing efforts are essential to allow the division to keep pace with the statistical demands arising from new technologies that are being applied to measurement systems and metrology. The health and activities of this division are crucial elements of the success of future NIST research.

The Statistical Engineering Division is located primarily at NIST Gaithersburg, where the staff are split into two groups: the Measurement Process Evaluation Group and the Statistical Modeling and Analysis Group. In addition, a group of staff from this division work at NIST Boulder where they are close to collaborators in the EEEL, CSTL, PL, and MSEL divisions located on that campus. Projects in a wide variety of fields are currently under way in the Statistical Engineering Division. Below, the panel describes several ongoing activities, but these efforts are just a few examples of the division's many successful projects.

The project highlights discussed in this section fall into three categories: Bayesian methodology, uncertainty analysis for key comparisons, and uncertainty analysis for process measurements. In the first area, the division has made major contributions through its work on Bayesian metrology. A fundamental problem in metrology is the assessment and assignment of realistic uncertainty to measurement results. In many complex problems, such as the analysis of high-throughput measurements, high-dimensional data, and complex dynamical systems, it is important to combine expert knowledge and prior information with physical measurements. The researchers in the Statistical Engineering Division have adopted the Bayesian framework to solve these sorts of problems. This framework provides a scientific basis and formal approach to utilizing scientific knowledge and prior information to yield better design of experiments and testing strategies. The application of this approach has produced a number of key achievements in the past year in the areas of interlaboratory intercomparisons, international key comparisons among national measurement institutes (NMIs), elicitation of prior information to calculate uncertainties, and development of nonparametric Bayesian models using empirical distributions.

One example of the important applications of Bayesian methodology is the international study of the sublethal effects of fire smoke on survivability and health, a joint project between the division and the NIST Building and Fire Research Laboratory. The goal was to obtain consensus values and uncertainty measures for lethal and incapacitating toxic potency values for large numbers of building materials based on data from the many different studies that have been published. The challenge was that the quality of the data varied greatly from study to study. Statistical Engineering Division researchers developed a Bayesian hierarchical model to combine the data from different studies with and without uncertainty measures by constructing vague priors at the lowest level of the hierarchy. The results of this project have had a large impact on the building industry at both the national and international level, and the success of the method attracted a great deal of interest from other researchers at NIST.

In the area of key comparisons and uncertainty analysis, the division has taken a lead in international efforts to establish equivalence among the many national standards organizations throughout the world. The mechanism for these efforts is the Mutual Recognition Agreement among the NMIs and regional metrology organizations that belong to the International Committee for Weights and Measures (CIPM). In this work, the greatest challenge for the division has been to develop a set of sound statistical design and analysis procedures to be used in interlaboratory studies for establishing equivalence of national standards. Key comparisons have five critical phases: (1) agreement among NMI scientists on the specific transfer standard (and/or measurement process), (2) design of the multinational experiment, (3) data collection at each NMI, (4) determination of the reference value and assessment of standard uncertainty at each NMI, and (5) determination and reporting of the level of equivalence among the participating NMIs and the related uncertainties. In the past year, division statisticians have developed a unified approach to experimental design and analysis to be applied in the work on key comparisons. Facilitation of key comparisons is an important element of NIST's support of the United States in the recent trend toward open markets and globalization.

The value of the division's expertise in data comparison can be seen even in comparisons that predate the MRA. Data for comparison of laboratories' realizations of the International Temperature Scale were collected over several years by 15 laboratories around the world prior to the signing of the MRA. As a result, no information was available as to whether the submitted components of uncertainty were for an individual measurement or for the mean of replicated measurements. Other problems related to determining how each uncertainty component contributed to the measurement error of the process, what uncertainties were associated with the standard platinum resistance thermometers used as transfer instruments, how to appropriately compute coverage factors to obtain expanded uncertainties with correct confidence levels, and, finally, how to explain the effects arising from diverse paths for computing temperature differences across subsets of laboratories. Working jointly with the NIST Chemical Science and Technology Laboratory (CSTL) and two laboratories in Germany and Australia, the Statistical Engineering Division was able to overcome all of these challenges and to produce useful results from the comparison data. These results are having a significant impact on the international temperature standards and on the sales of temperature-related equipment or services between different countries. The success of this key comparison makes it a role model for future comparisons.

Another project that is a benchmark example of what is possible in a key comparison is the division's work on statistical uncertainty analysis for the comparison of resistance standards. The NIST Electronics and Electrical Engineering Laboratory (EEEL) and 14 other NMIs participated in the CIPM Consultative Committee for Electricity and Magnetism's Comparisons of Resistance Standards. Two types of dc resistors were used as traveling standards and were measured by different laboratories at different time periods. Systematic drifts of the traveling standards and laboratory measurement uncertainties were the main causes of discrepancies among the measurements. However, the Statistical Engineering Division staff developed an accurate statistical model based on linear regression to combine the measurements, and this model now can provide a basis for calibrating the high-resistance standards of the laboratories' customers.

Another important contribution of the Statistical Engineering Division is the study of uncertainties associated with process measurements. Data from these types of measurements, such as fluid-flow measurements, information about high-speed optoelectronic signals, and measurement of spray characteristics, occur frequently in the NIST laboratories. In the past year, the division staff have worked collaboratively with other NIST scientists on solving difficult problems, using expertise in statistical signal processing, time series, and statistical smoothing techniques.

One such joint project is with the CSTL on flow measurements for multimeter transfer standards. The result of this work is the implementation of an in-house prototype system to evaluate in detail the behavior of dual meter systems. With new understanding from this prototype, an efficient experimental design has been tested and then modified specifically for the international key comparison setting. In conjunction with the experimental design development, methodology for data analysis has been put into place for the initial key comparison, for which NIST is the pilot laboratory. The time spent on this project was highly leveraged, as the new protocol is serving as the prototype for the other five areas under study in the CIPM's Working Group for Fluid Flow and as the basis for all future international flow comparisons.

The importance of the division's expertise and experience in statistical issues related to signal processing can be seen in the work with EEEL on high-speed optoelectronic measurements. Division staff have developed state-of-the-art statistical signal processing techniques to reduce the random component of the timing error and the systematic component of time-base distortion in these measurements. Using a regression spline model, the average of the aligned signals is interpolated onto an equally spaced time grid based on estimated time-base distortion, and the resulting power spectrum is then corrected for jitter effects by an estimated multiplier. The laboratory's new measurement capability will be used to support industrial applications in the areas of gigabit ethernet networks, fiber channels, optical telecommunications, and wireless communications. The results have been published in *IEEE Transactions on Instrumentation and Measurements.*

Program Relevance and Effectiveness

As demonstrated by the preceding examples, the efforts of the Statistical Engineering Division have a broad impact on the work of the NIST scientists and engineers with whom the division collaborates. Since NIST's mission and activities focus on measurement science, the division staff have developed some capabilities that are unique within the scientific community. These capabilities include expertise and experience in techniques for statistical uncertainty analysis for measurement science (i.e., measurement processes) and statistical methods for metrology. These are important capabilities, and the panel firmly believes that the division can and should play a pivotal role in NIST's support of U.S. industry by promoting industrial statistics and by helping to link key statistical groups in academia and industry and at U.S. national laboratories. For the past few years, the division has appropriately focused on rebuilding its reputation and maintaining a strong portfolio of work within NIST (and ITL), but now that the division is growing stronger, increased focus on external relationships and responsibilities should be the natural next step.

Methods for technology transfer is one area in which external organizations might benefit from learning more about the Statistical Engineering Division's projects and approaches. The division staff have an excellent reputation for their ability to turn research projects into standard methods, tools, and software that can be easily used by NIST scientists. This is a type of technology transfer, and these products are particularly valuable because they continue to raise the statistical competency of NIST scientists while avoiding a pitfall commonly experienced in other organizations—that is, scientists becoming dependent on statisticians for experimental analysis, thereby limiting the time that the statisticians have to push the leading edge of statistical research and development. Not only are NIST statisticians adept in technology transfer within NIST, but division staff are also actively involved in general education about statistical uncertainty and promote statistical methodologies by offering short courses and workshops and by producing the Web-based *NIST/SEMATECH Engineering Statistics Internet Handbook*.[13] Other statistics organizations in industry and at the national laboratories struggle with technology transfer and could learn a great deal from the division's successes in this area.

The Statistical Engineering Division plays an important role in the national and international metrology communities through contributions to documents and handbooks of standard methodology, promotion of statistical approaches to metrology, collaboration on international experiments, participation in international metrology organizations, publications in leading journals in metrology, and assistance to other NMIs through training and collaborations. The value of the division's work is known and appreciated throughout relevant physical sciences communities as a result of the dissemination efforts mentioned above and the large number of publications that result from the division's collaborative efforts and which appear in subject-matter scientific journals.

However, the statistical sciences community should also be benefiting from the division's unique expertise and experiences. Division staff do publish in statistics journals and present at statistics conferences, and the panel was pleased to see a surge in dissemination of the division's research in peer-reviewed journals, as suggested in last year's assessment report. Nonetheless, the burden is still on the division to facilitate stronger interactions with the statistical sciences community as a whole. One element of achieving higher visibility in the statistics discipline and maximizing the division's impact on the statistics community should be that of generalizing the methodologies from specific problems to show their relevance to solving a wider range of similar problems and making these results broadly available through publications in leading statistical journals.

Division Resources

Funding sources for the Statistical Engineering Division are shown in Table 8.9. As of January 2002, staffing for the division included 19 full-time permanent positions, of which 17 were for technical professionals. There were also 12 nonpermanent or supplemental personnel, such as postdoctoral research associates and temporary or part-time workers.

[13]The *NIST/SEMATECH Engineering Statistics Handbook* is available online at <http://www.itl.nist.gov/div898/handbook/index.html>.

TABLE 8.9 Sources of Funding for the Statistical Engineering Division (in millions of dollars), FY 1999 to FY 2002

Source of Funding	Fiscal Year 1999 (actual)	Fiscal Year 2000 (actual)	Fiscal Year 2001 (actual)	Fiscal Year 2002 (estimated)
NIST-STRS, excluding Competence	2.9	3.0	3.4	3.7
Competence	0.5	0.6	0.3	0.5
STRS—supercomputing	0.1	0.0	0.0	0.0
ATP	0.0	0.0	0.2	0.3
Measurement Services (SRM production)	0.0	0.0	0.1	0.5
OA/NFG/CRADA	0.1	0.1	0.1	0.4
Total	3.6	3.7	4.1	5.4
Full-time permanent staff (total)[a]	23	19	17[a]	19

NOTE: Sources of funding are as described in the note accompanying Table 8.1.
[a]The number of full-time permanent staff is as of January of that fiscal year, except in FY 2001, when it is as of March.

As noted above, the progress evident since the hiring of the new division chief in the fall of 2000 is extraordinary. Morale is now high, top-rate visiting researchers have been engaged to fill technical gaps, and new junior personnel have been hired (in spite of difficulties due to the governmentwide hiring freeze imposed by the change in administration). It is clear that the division is moving quickly in exactly the right direction. However the division's recovery is still at a somewhat fragile stage, and continued support from ITL and NIST management will be needed to fulfill the division's long-term goals. A 5-year plan is in place to increase the division's full-time permanent technical staff from 16 to 24, and the division is on track in year 2 of the plan. The growth should be a combination of junior and senior hires, and, to continue to move forward, the division will require a commitment from management to steadily increase the division's core support.

The Statistical Engineering Division has done well in competitions for internal research and development funds, and this year has seen a significant increase in the division's activities related to the production of standard reference materials (SRMs). This growth is due primarily to the staff's outstanding development of educational courses for outreach to NIST researchers, who have in turn realized the opportunities presented by working with the division on SRM-related projects. The panel believes that the staff should aggressively continue these outreach activities, which produced the surge in national and international SRM work.

The panel continues to be concerned about the relative isolation of the Statistical Engineering Division in its current location at NIST North. The issues related to this recurring concern have been discussed at length in many past assessment reports. If NIST is to obtain the maximum value possible from the division, the panel strongly urges NIST management to consider relocating this division to the main campus. If relocation is not an option in the near term, NIST management should actively work with ITL and division management on other creative approaches to solving this problem.

9

Measurement Services

PANEL MEMBERS

Kenneth O. MacFadden, Honeywell, Inc., *Chair*
David Abell, Agilent Technologies
John M. Ball, U.S. Army Primary Standards Laboratory, Redstone Arsenal
Anthony J. Berejka, Independent Consultant, Huntington, New York
Duane J. Christy, Mahr Federal, Inc.
Terrence M. Conder, 3M
L.F. Eason, North Carolina Department of Agriculture and Consumer Services
David Holkeboer, Independent Consultant, Ft. Myers Beach, Florida
M. Lynne Neumann, Laboratory Accreditation Bureau
James D. Olson, The Dow Chemical Company
Cecil W. Schnieder, CEC Technologies, PC
Ralph Truitt, Corning Incorporated
David H. Youden, Eastman Kodak Company

Submitted for the panel by its Chair, Kenneth O. MacFadden, this assessment of the NIST Measurement Services Program is based on a formal meeting of the panel on April 3-5, 2002, in Gaithersburg, Md., and on documents provided by NIST.

PURPOSE OF THE REVIEW

The Panel for Measurement Services was established because of a continuing recognition by both the Board on Assessment of NIST Programs and the leadership of NIST of the importance of managing and assessing multidisciplinary programs in a way that transcends the organizational lines of the institute. Measurement services (Standard Reference Materials, Standard Reference Data, and Calibration Services, and the National Voluntary Laboratory Accreditation Program) are a long-standing part of NIST's portfolio of programs, and this review is intended to consider how well these services are being developed, supported, and delivered throughout the NIST Measurement and Standards Laboratories. This panel includes members who participate in three of the seven standing laboratory assessment panels (the panels for the Physics Laboratory, the Manufacturing Engineering Laboratory, and the Chemical Science and Technology Laboratory) in addition to at-large members appointed especially for this review.

The panel was charged with assessing the quality of measurement services carried out by the NIST laboratories and disseminated by the NIST Office of Measurement Services, with a focus on evaluating the following:

- The range of measurement services within the NIST laboratories;
- How measurement services are managed and coordinated across NIST, with emphasis on functions performed at the NIST level, including how effectively NIST maintains quality control over its measurement services;
- How effectively NIST coordinates its measurement services with customer needs in industry, government, and academia (including how NIST gathers and uses information on customer needs and customer feedback);
- How effectively current NIST measurement services meet industry needs; and
- The adequacy of NIST human resources, equipment, and facilities dedicated to measurement services, with an emphasis on the challenges of refreshing skill sets and equipment.

In a meeting with the panel, the NIST director posed these additional questions:

- Does NIST approach its service planning effectively from a strategic point of view?
- Does NIST measure the impact of its measurement services successfully?
- Is NIST ensuring that U.S. industry has access to NIST-traceable measurements on all appropriate scales?
- Does NIST effectively align customer expectations with its goals and resources?

NIST MEASUREMENT SERVICES ACTIVITIES

NIST presented the panel with a summary of its measurement services activities, which are viewed by the institute as a primary mechanism for transferring the results of the investments it makes in measurement science and engineering. The services provide industry with direct links to high-accuracy, primary national measurement standards, calibration of measurement capabilities, and national databases. Every laboratory at NIST supports measurement services activities. The measurement services are these:

- *Calibration services:* Direct calibration of instruments and their traceability to national standards;
- *Standard Reference Materials (SRMs):* The NIST-certified reference materials traceable to primary national standards and suitable for self-calibration in customers' laboratories;

TABLE 9.1 Total Budget for Measurement Services as of June 15, 2002 (in millions of dollars)

	Technology Services	Laboratories	Total
Standard Reference Data	3.1	4.4	7.5
Calibrations	0.9	6.8	7.7
Standard Reference Materials	3.9	6.7	10.6
National Voluntary Laboratory Accreditation Program	4.4	0.2	4.6
Total	12.3	18.1[a]	30.4

[a]Allocated to those laboratories that support measurement services activities.

- *Standard Reference Databases (SRDs):* Accessible databases containing data from NIST and other sources that have been critically evaluated to ensure quality and standardized nomenclature; and
- *National Voluntary Laboratory Accreditation Program (NVLAP):* Accreditation of laboratories performing specific tests.

The budget for NIST measurement services is shown in Table 9.1.

Measurement services programs are full cost recovery programs with the exception of SRD, which operates under special legislation (15 U.S.C. 290). NIST currently provides more than 500 calibration services and more than 1,300 SRMs, supports more than 80 databases and online data systems, and has performed close to 800 accreditations.

Over time, NIST has used a variety of organizational structures to manage and provide its measurement services. Today, the NIST Measurement and Standards Laboratories are responsible for the technical aspects of NIST measurement services. The seven NIST laboratories individually contain the expertise in measurement capability and technical management that underpins NIST services. The NIST Technology Services unit provides support and business services for NIST measurement services. Under this organizational structure, the majority of planning for individual measurement services comes from the individual NIST laboratories, as an outgrowth of their normal planning exercises. Oversight of the NIST measurement services is provided by the Measurement Services Advisory Group (MSAG), which is composed of the directors of the seven NIST laboratories and the director of Technology Services. The MSAG meets approximately 10 times per year to review NIST policy issues and the quality of services provided to NIST customers. The MSAG efforts seek to ensure quality service and technology to NIST measurement services customers and uniform policies for measurement services throughout NIST.

ASSESSMENT OF NIST MEASUREMENT SERVICES

The assessment of NIST measurement services should include both an assessment of the technical merit of the relevant research programs in the Measurement and Standards Laboratories and an assessment of the quality of services provided through Technology Services. During this panel's review of the information provided by NIST, it was often difficult to separate the technical components that lead to the services provided from the process of providing the services. As much as possible, the panel focused its efforts on the service component of measurement services, since the technical merit of the projects under way in each of the NIST laboratories has been reviewed in the previous chapters of this volume by other panels.

In addressing the components of its charge, the panel decided to assess measurement services from the perspective of a service-supplier business. The charge to the panel, and hence the assessment, falls naturally into three categories: customer needs, NIST capabilities, and operations management. In this light, the range of services appears to be meeting customer needs through its flexible, distributed management structure and a highly talented technical staff dedicated to customer service. However, as discussed below, there appears to be a need for more NIST-wide, servicewide strategy, planning, policy, sharing, and accountability.

Customer Needs

The panel is impressed with how actively NIST staff seek customer input. Staff members utilize a variety of mechanisms to obtain customer input and feedback on needs in measurement services. They participate in technical conferences, visit industrial customers, and participate in national and international standards committees. They utilize industry road maps and technology forecasts to understand anticipated developments. They organize NIST-sponsored workshops to convene industry representatives in order to consider specific areas of measurement needs. Independent surveys—for example, direct surveys and input from the National Measurements Requirements Committee of the National Conference of Standards Laboratories International (NCSLI)—are used to seek customer feedback on services provided and input on services desired.

The panel found definite awareness of and interest in customer needs at the working level for all the services it examined. Pride in customer service is evident throughout the staff that provides measurement services.

Responsiveness to customer needs is also apparent throughout measurement services. Maintaining the preeminence of its expertise internationally in measurements and standards science is the most basic way in which NIST responds to its customer needs for measurement services. The laboratories are also clearly expanding their services and capabilities as necessary in response to customer requests for new or improved services.

Staff respond not only to technical requests but also to feedback on customer service. An outstanding example of this type of response is the Web-based NIST Information System to Support Calibrations (ISSC)—an information system that can manage almost every aspect of information related to calibration service requests. Purchase orders and test requests can be documented, equipment tracked, calibration progress monitored, and reports issued through this system. It can be used for internal control purposes and can also be accessed by customers through a password-protected system in order to check the status of their service requests. The system gives customers timely information on their calibrations and provides NIST with a tool to analyze and improve calibration turnaround time.

Another service improvement introduced in response to customer needs is the recent clarification of the NIST Traceability Policy. This comprehensive statement of NIST policy concerning its support of measurement traceability was placed on the NIST Web site along with frequently asked questions about traceability. The policy, which makes clear the burden of private parties making claims of traceability to NIST to prove that traceability to their customers, has been frequently accessed over the Web. NIST provides methods to assist users in establishing traceability, including accreditation services, through NVLAP.

NIST has also responded to customer needs with new methods for delivery of service, such as the use of secondary standards suppliers through its NIST Traceable Reference Material (NTRM) Program for gas suppliers and through the use of the Internet to perform certain electrical calibrations remotely (“e-calibrations”).

It is clear to the panel that the MSAG has been an indispensable organizational structure for identifying customer needs that cut across all NIST measurement services. The MSAG has been responsible for developing and implementing policy to meet those needs—for example, its response to the need for a clear, NIST-wide statement on traceability. As the MSAG model of leadership matures, the panel expects that it will have an even greater positive impact on the quality of NIST measurement services and their responsiveness to customer needs.

While the panel was pleased with much of what it saw occurring in measurement services, it believes that opportunities exist to strengthen NIST's overall portfolio of services and to increase its effectiveness for customers.

Significant customer input and feedback on individual services is gathered by NIST staff members, but the panel finds no mechanism for rolling that feedback up to a higher level and for sharing it among staff across NIST who work on measurement services. While some of this information is likely unique to particular services, much of it may reflect more general issues and concerns. The MSAG does provide a mechanism for gathering and analyzing customer feedback more universally across NIST, but this still appears to be happening in a somewhat ad hoc fashion. To get full benefit of the information that NIST staff currently gather with respect to their customers and from them, NIST needs a more formal process for centrally capturing that information, analyzing it, and sharing it across the institute.

The panel is impressed with the capabilities of the ISSC and the opportunities that it provides for transferring information to and gathering information from customers. The panel sees value in expanding the use of such an online system to all NIST measurement services and to measurement services provided internally to NIST customers. The MSAG should examine the value of expanding the availability of ISSC-like capabilities throughout the measurement services portfolio.

The capability to gather and analyze the "customer voice" obligates NIST, if it wishes to be perceived as responsive, to respond to the customer with information on its own performance. To that end, and also to improve the internal management of services, measurement services need more uniform, easily understood metrics that can be presented to the customer and staff succinctly. These so-called dashboard metrics could track and present data on such process attributes as turnaround time, service backlog, and customer satisfaction. Internally, NIST should develop metrics to understand customer needs for speed of service versus cost, and it should adjust its processes and services according to the analysis of those metrics over time. NIST is constrained to price services for cost recovery, and it is important to evaluate whether customers perceive the value for the price and to adjust services accordingly.

The panel sees opportunities to expand outreach to the end users of NIST services. NIST presented examples of effective and innovative dissemination methods—Web-based data and services; measurement training seminars; and Recommended Practice Guides, booklets that provide practical, easy-to-understand advice and guidance on performing common measurement techniques, addressed to researchers throughout the country who may have recourse to these measurement methods only infrequently. Each of these dissemination tools is being used effectively in specific areas of the measurement services program—for example, Recommended Practice Guides have been issued primarily in areas related to materials science measurements. The panel believes that MSAG should examine such methods for broader use across measurement services. The panel also notes that few of the NIST laboratories seem to have strong ties to NIST Manufacturing Extension Partnership Centers. These centers provide NIST with another opportunity to disseminate the results of its work, and they seem to be particularly appropriate vehicles for expanding customer awareness of measurement services.

NIST presented the panel with results of retrospective studies of the economic impact of specific NIST services and products. The panel suggests that NIST utilize prospective marketing studies for proposed new services. This would provide the MSAG with a perspective on the primary customer for its services and on the secondary effects that the services might have, prior to the commitment of resources to service development and support. With such information, NIST could better target its investments to areas with maximum impact on U.S. competitiveness.

NIST Capabilities

Regarding the most important consideration with respect to NIST capabilities, the quality of the staff members who work on measurement services, the panel is impressed. Technical staff developing and supporting measurement services are, in general, world-class, and in many instances best-in-the-world practitioners of their particular measurement expertise. The morale of technical staff members supporting measurement services appears to be high, and their pride in the services they provide to customers is clearly evident. Commitment to quality of service and to appropriate traceability is apparent in their approach to their work. In addition to the measurement experts who directly provide the services, NIST also draws on the in-house expertise of its world-class statisticians, who assure the correct analysis and reporting of uncertainty in the values assigned to SRMs and measurements, and of accreditation experts in NVLAP. Overall, NIST has an excellent human resource base on which to support its measurement services.

In general, the equipment supporting measurement services is good, although some significant exceptions may exist, as noted in the laboratory assessments in previous chapters of this report. Significant enhancements in capability are anticipated when the Advanced Measurement Laboratory (AML) is available for occupancy. This facility will enable NIST to continue world-class measurement services in areas of substantial importance for U.S. industry.

As with all organizations, NIST struggles under the limitations of its funding and other resources, and so effective use of these resources is critical. Because of the current decentralized management of measurement services, the panel was not able to obtain a clear picture of the total resources devoted to these services. Several areas of possible concern presented themselves.

No overall demographics for staff that develop and support measurement services are available. NIST provided no data to indicate whether the portfolio of measurement services rests on a base of staff with the appropriate age and experience to ensure continuation of core services into the future, or whether the available staff resources are being used appropriately. For example, it appeared to the panel in its brief time in the laboratories that a number of Ph.D.'s are spending inordinate amounts of time on technician-level work. Greater use of technicians would increase the overall efficiency of measurement services and enable NIST to better respond to more of its customer needs. Consideration of NIST-wide measurement services staff demographics by the MSAG might enable better utilization of staff, better succession planning, and better cross-training of staff involved in measurement services.

No overall plan for equipment and facilities is in place. MSAG does not have a broad picture of which programs may be in need of major equipment upgrades in the near future in order to ensure continuity of services; nor is there a plan to ensure the required facilities for those measurement services programs that will not be housed in the new AML.

The panel does not understand the policy regarding fees for SRDs. Some SRDs are available for purchase, while others are given away at no charge. The panel wonders if a uniform policy for charging would generate more complete cost recovery and additional revenues for SRD development.

The panel was presented with data that indicate that SRM sales, an important source of revenue for measurement services through fees, are decreasing over time. No analysis of this trend was presented to the panel. These sales may be decreasing for positive reasons—for example, the increased use by industry of secondary standards traceable to NIST such as NTRMs—or for negative reasons, such as lack of industry interest in specific SRM offerings or the higher cost of NIST SRMs in comparison with the cost of NRTMs. The MSAG needs to investigate the reasons for this drop-off in order to understand it and take appropriate actions. On a similar note, even though there appears to be a conscious effort to assess NIST impact and the value of particular measurement services, a few SRMs were rather low-technology in approach and might be migrated out-of-house in order to free up NIST resources to work on development and support of SRMs requiring more sophisticated technical expertise. The MSAG should review the SRM portfolio to determine whether such opportunities exist.

Operations Management

The flexible, distributed management of measurement services as currently embodied through the sharing of responsibilities between the laboratories and Technology Services, with coordination occurring through the MSAG, appears to be working well. Placing the responsibility for identification of customer needs and for technical decision making in the laboratories, which have the technical expertise and customer knowledge needed to perform these tasks, makes sense and is serving NIST well. At the same time, the coordination being performed by the MSAG is working well and has resulted in some significant improvements in policy and use of the resources available for measurement services.

The current management system works well to ensure that delivered services are reliable, and responsiveness to customers' expressed needs is strong. The resulting culture existing among measurement services staff places a high value on precision, accuracy, and appropriate traceability of measurements. Extensive use of domestic and international key comparisons and of check standards was observed. Partnerships with other national measurement institutes (NMIs), which have focused primarily on technical collaborations to ensure the quality of a measurement performed in both institutes, are now being expanded to agreements to accept one another's standards in certain areas.

The panel believes that the overall operations of measurement services could be strengthened by the development of a strategic plan. While each current program appears to meet an identified customer need, the panel and, indeed, MSAG have no way of judging whether the portfolio as a whole addresses the most critical customer needs. Strategic planning for measurement services could enable the MSAG to target its investments toward programs and measurements with the highest leveraging in the U.S. economy. It could serve as the basis for pursuing additional targeted collaborations with other NMIs in order to maximize the services available to U.S. customers. The Strategic Focus Areas identified in the ongoing NIST-wide strategic planning exercise provide an excellent template upon which a measurement services plan can be built.

The panel also sees great benefit to be had from sharing of best practices. The panel saw excellent mechanisms for communicating with customers, delivering services more efficiently, and expanding services available to U.S. industry—for example, the ISSC, the use of e-calibrations, and the recent cooperative agreement with Germany's Physikalisch Technische Bundesanstalt for certain SRMs. Many of these practices could be more widely utilized to good effect. It appears that no process is in place for sharing, dissemination, and implementation of such "best practices" NIST-wide. The panel suggests that the MSAG devote some time to such an exercise.

As noted above, the panel also believes that management of measurement services could be improved if the MSAG developed and used common metrics for the performance of measurement services NIST-wide. Currently, metrics are monitored for each service at the level of the service provider. It does not appear that metrics are universally applied for all services. Even if some metrics are being used for all services offered, this information still has to be rolled up into overall metrics for measurement services so that the MSAG has the information it needs to assess performance and make subsequent programmatic decisions.

NIST has in place a NIST quality system to document the steps it takes to ensure the quality of the calibration and testing services on which its customers depend. Without meaning to imply that the current quality system is insufficient, the panel suggests that the NIST quality system more visibly conform to the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) systems that its customers use and are familiar with. The panel suggests that NIST self-declare voluntary compliance with those provisions of ISO/IEC 17025 that are applicable and appropriate to the case of an NMI. Adoption of ISO/IEC 17025 as a template for describing the NIST calibration and testing services program would make it easier for NIST customers (many of whom are ISO/IEC 17025-compliant or accredited) and other outsiders to understand certain aspects of the NIST measurement services program. Furthermore, some documentation of the manner in which NIST responds to specific clauses of the standard would provide valuable guidance to other calibration laboratories for developing or assessing their own quality programs. The MSAG should accept responsibility as quality coordinator for the measurement services programs and ensure that the quality system is implemented across NIST in all applicable programs.

MAJOR OBSERVATIONS

The panel presents the following major observations:

- The current system of flexible distributed management of NIST measurement services provides the capacity for positive customer relationships and responsiveness, excellent technical decision making, and structured coordination through the internal Measurement Services Advisory Group.
- Excellent grassroots connection with the customers of measurement services is evident, and much information on customer needs is gathered through such channels. To extract maximum value from such information, a process is needed to gather and analyze it centrally and to disseminate it across NIST.
- The MSAG should develop an overall strategic plan for measurement services that is consistent with the overall NIST strategic plan being developed. This would help ensure that the services offered are addressing the most critical customer needs and are providing those measurements that have the most leverage in the U.S. economy. The Strategic Focus Areas identified in the NIST strategic planning exercise provide a good template on which to build a measurement services strategy. The plan would also provide the basis for the needed facility and staff succession plans.
- While staff involved in measurement services receive significant feedback from their customers with respect to customer needs, the use of prospective marketing studies would help the MSAG better target those services that would have the greatest impact on U.S. competitiveness.
- Metrics for measurement services are needed to provide the MSAG with tools to assess performance and take necessary programmatic action. The panel recommends that the MSAG develop “dashboard” metrics that can also be used to give customers and staff succinct, easy-to-understand

measures of NIST performance and demonstrate NIST's commitment to continual improvement in its programs and services.

- The MSAG should engage in a "best practices" exercise to propagate the use of the most effective and innovative means of identifying and meeting customer needs.
- The MSAG should expand the NIST quality system to include a statement of voluntary compliance with the ISO/IEC 17025 quality standard where applicable and appropriate to a national measurement institute.

Appendixes

Appendix A

Charge to the Board and Panels

NIST CENTENNIAL 1901-2001

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

NOV 30 2001

MEMORANDUM FOR Board on Assessment of NIST Programs and Its Panels

From: Karen H. Brown
Acting Director

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

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

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

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

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

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

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

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

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

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

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

cc: Executive Board
Program Office
Dorothy Zolandz

Appendix B

Agendas for Meetings of the Board on Assessment of NIST Programs

DECEMBER 6, 2001

National Institute of Standards and Technology, Gaithersburg, Maryland

Wednesday, December 5

7:00 p.m.	Dinner, Board and New Panel Members

Thursday, December 6

Open Session

8:30 a.m.	Welcome and Introductions Linda Capuano, Chair, NRC Board on Assessment of NIST Programs
8:45 a.m.	Introduction to NRC and Overview of Board/Panel Operations Dorothy Zolandz, Director, Board on Assessment of NIST Programs, NRC
9:15 a.m.	NIST Director's Address Karen Brown, Deputy Director, NIST
10:00 a.m.	Break
10:15 a.m.	Overview of NIST Measurement and Standards Laboratories
11:00 a.m.	Tours of Major Units for New Panel Members Board Goes into Executive Session

Closed Session

11:00 a.m.	Executive Session
	Discuss Board balance and composition Review conclusions from 2001; identify themes for 2002
12:30 p.m.	Lunch
1:15 p.m.	Executive Session: Themes for 2002 (continued)

Open Session

1:45 p.m.	Update on NIST Strategic Plan, Karen Brown
2:15 p.m.	Update on Coordination of Microelectronics Program Steve Knight, Office of Microelectronics Programs
2:45 p.m.	NIST Efforts Related to Counterterrorism, Karen Brown
3:15 p.m.	Open Discussion with NIST OU heads
	Themes for 2002 assessment Process issues 2002 cross-cut assessment
4:00 p.m.	Executive Session—Wrap Up
4:30 p.m.	Adjourn

MAY 9-10, 2002

National Academy of Sciences Building, Washington, D.C.

Thursday, May 9, 2002

Closed Session

8:00 a.m.	Continental Breakfast
8:30 a.m.	Review of Panel Findings (Laboratory Panels and Cross-cut Panel) Begin identifying overarching issues 9:30 a.m.—Janet Fender, Teleconference to Discuss Physics Laboratory
11:00 a.m.	Discussion of Cross-cut Process: Lessons Learned from 2001 and 2002
11:30 a.m.	Lunch

12:30 p.m.	Discussion of Overarching Themes and NIST Strategic Planning
2:30 p.m.	Break
2:45 p.m.	Discussion of Potential Quantitative Metrics for NIST Assessment, and Potential Process Changes
5:00 p.m.	Adjourn for Day
6:15 p.m.	Dinner

Friday, May 10, 2002

7:30 a.m.	Continental Breakfast
8:00 a.m.	Follow-up Discussion of Overarching Issues, Metrics, and Process Prepare for Discussion with NIST Managers

Open Session

11:00 a.m.	Discussion with NIST Director, Deputy Director, OU Heads, and Other NIST Managers 2002 assessment results Quantitative metrics Assessment process and possible changes
1:00 p.m.	Lunch

Closed Session

2:00 p.m.	Executive Session
2:30 p.m.	Adjourn

Appendix 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 2002 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.

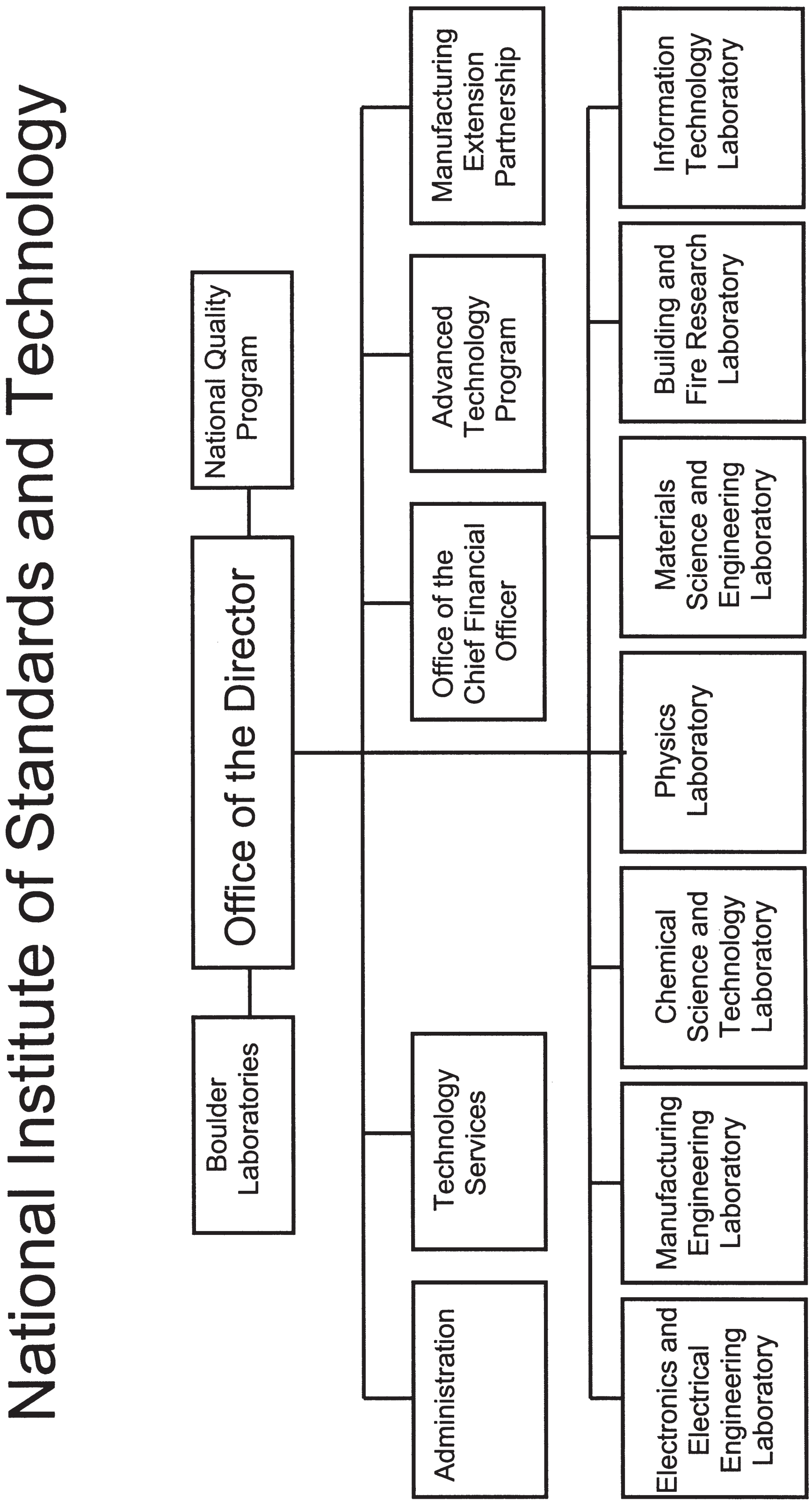
MISSION OF NIST

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.

Appendix 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

Structures Division
Building Materials Division
Building Environment Division
Fire Research Division
Codes and Standards
Office of Applied Economics

Information Technology Laboratory

Mathematical and Computational Sciences Division
Advanced Networking Technologies Division
Computer Security Division
Information Access Division
Convergent Information Systems Division
Information Services and Computing Division
Software Diagnostics and Conformance Testing Division
Statistical Engineering Division

Appendix E

Acronyms and Abbreviations

AAMACS—advanced automated master angle calibration system
AC—alternating current
ACI—American Concrete Institute
ACM—Association for Computing Machinery
ADCL—Accredited Dosimetry Calibration Laboratories
ADL—architecture description language
AED—atomic emission detection
AES—Advanced Encryption Standard; Auger electron spectroscopy
AFLAP—Armed Forces Laboratory of Applied Pathology
AFM—atomic force microscopy/microscope
AIGER—American Industry/Government Emissions Research
AMD—Advanced Micro Devices
AMDIS—Automated Mass Spectral Deconvolution and Identification Software
AML—Advanced Measurement Laboratory
AMO—atomic, molecular, and optical
ANSI—American National Standards Institute
API—application programming interface
ASHRE—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
ATSC—Advanced Television Systems Committee
BACnet—Building Automation and Control Network
BEC—Bose-Einstein condensates
BEES—Building for Environmental and Economic Sustainability
BFRL—Building and Fire Research Laboratory

BioMEMS—biomicroelectromechanical systems
BIPM—Bureau International des Poids et Mésures
BISR—Bioinformatics Software Resource
BLAS—Basic Linear Algebra Subprograms
BMCD—Biomolecular Crystallization Database
BVL—Biomarker Validation Laboratory
CAD—computer-aided design
CAM—computer-aided manufacturing
CARB—Center for Advanced Research in Biotechnology
CBEFF—Common Biometric Exchange File Format
CCM—Consultative Committee for Mass and Related Quantities
CCT—Consultative Committee on Temperature
CD—critical dimension; compact disk
CE—capillary electrophoresis
CEC—capillary electrochromatography
CGM—Computer Graphics Metafile
CHRNS—Center for High Resolution Neutron Scattering
CIF—common industry format
CIO—chief information officer
CIP—critical infrastructure protection
CIPM—Comité International des Poids et Mésures
CIRMS—Council on Ionizing Radiation Measurements and Standards
CISPR—International Special Committee on Radio Interference
CIS2—CIMsteel Integration Standards
CMM—coordinate measuring machine
CMOS—complementary metal-oxide semiconductor
CMRL—Construction Materials Reference Laboratory
CMVP—Cryptographic Module Validation Program
CNBT—Cold Neutrons for Biology and Technology
CONSAFE—Construction Systems and Safety
CONSIAT—Construction Integration and Automation Technology
CORM—Council for Optical Radiation Measurements
CRADA—cooperative research and development agreement
CRDS—cavity ring-down spectrometer
CSEAT—Computer Security Expert Assist Team
CSTL—Chemical Science and Technology Laboratory
CU—University of Colorado
C-V—capacitance-voltage
CVD—chemical vapor deposition
CV-ID-ICP-MS—cold vapor isotope dilution inductively coupled plasma mass spectrometry
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 time-of-flight spectrometer

DLMF—Digital Library of Mathematical Functions
DNA—deoxyribonucleic acid
DNS—Domain Name System
DOD—Department of Defense
DOE—Department of Energy
DOT—Department of Transportation
DRM—digital rights management
DTV—digital television
DUC—Document Understanding Conference
DUV—deep ultraviolet
DVD—digital versatile disk
EARS—Effective Affordable Reusable Speech-to-text
EB—electron beam
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
EPA—Environmental Protection Agency
EPRI—Electric Power Research Institute
EUV—extreme ultraviolet
FASCAL—Facility for Automatic Spectroradiometric Calibrations
FAST—financial agent secure transactions
FBI—Federal Bureau of Investigation
FCC—Federal Communications Commission
FDA—Food and Drug Administration
FDD—fault detection and diagnostics
FDS—fire dynamics simulator
FEMA—Federal Emergency Management Agency
FIATECH—Fully Integrated and Automated Technology
FIB—focused ion beam
FIMA—Federal Insurance and Mitigation Administration
FISH—fluorescence in situ hybridization
FRP—fiber-reinforced polymer
FTIR—Fourier-transform infrared
GaAs—gallium arsenide
GAMS—Guide to Available Mathematical Software
GC/MS—gas chromatography/mass spectrometry
GEC—Gaseous Electronics Conference
GEMnet—GSA Energy Management network
GIXPS—grazing incidence x-ray photoemission spectroscopy
GPS—Global Positioning System
GSA—General Services Administration
GSAS—general structure analysis system

HACR—High Accuracy Cryogenic Radiometer
H/D—hydrogen/deuterium
HDSA—High Density Storage Association
HDTV—high-definition television
HFBS—high-flux backscattering spectrometer
HFC—hydrofluorocarbon
HIV—Human Immunodeficiency Virus
HIVDB—HIV Protease Structural Database
HPC—high-performance concrete
HR—high resolution
HUD—Department of Housing and Urban Development
HVAC/R—heating, ventilation, air conditioning, and refrigeration
IAI—International Alliance for Interoperability
IAQ—indoor air quality
IC—integrated circuit
ICM—Internet Commerce for Manufacturing
ICP—inductively coupled plasma
IDEMA—International Disk Drive Equipment and Materials Association
IEA—International Energy Agency
IEC—International Electrotechnical Commission
IEEE—Institute of Electrical and Electronics Engineers
IETF—Internet Engineering Task Force
IFC—Industry Foundation Classes
IGERT—Integrative Graduate Education, Research, and Training
IGOR—data reduction and analysis software
IIEDM—Infrastructure for Integrated Electronic Design and Manufacturing
IKE—Internet Key Exchange
ILC—interlaboratory comparison
IM—intercomparison materials
IMPI—Interoperable Message Passing Interface
INAA—instrumental neutron activation analysis
IP—Internet Protocol; intellectual property
IPsec—Internet Protocol Security
IR—infrared
ISO—International Organization for Standardization
IT—information technology
ITF—Irradiation Testbed Facility
ITL—Information Technology Laboratory
ITRS—International Technology Roadmap for Semiconductors
ITS—intelligent transportation system
IUPAC—International Union for Pure and Applied Chemistry
JEDEC—Joint Electron Device Engineering Council
KC—Key Comparison
LADAR—laser detection and ranging
LANL—Los Alamos National Laboratory
LBNL—Lawrence Berkeley National Laboratory

LC—liquid chromatography
LCC—life cycle costs
LED—light-emitting diode
LFRD—load and resistance factor design
LISA—Laser Interferometer Space Antenna
LLC—Limited Liability Corporation (consortium)
LLNL—Lawrence Livermore National Laboratory
LS—liquid scintillation
MACS—multi-analyzer crystal spectrometer
MALDI—matrix-assisted laser desorption ionization
MANET—mobile ad hoc network
MBE—molecular beam epitaxy
MEF—mask enhancement factor
MEL—Manufacturing Engineering Laboratory
MEMS—microelectromechanical systems
MEP—Manufacturing Extension Partnership
MERLiN—modeling, evaluation, and research of lightwave networks
MFM—magnetic force microscope
MOS—metal-oxide semiconductor
MOSFETS—metal-oxide semiconductor field-effect transistors
MOU—memorandum of understanding
MPD—Measurement Program Description
MPEG—Motion Picture Experts Group
MPLS—multiprotocol label switching
MQA—measurement quality assurance
MRA—Mutual Recognition Agreement
MRAM—magnetic random access memory
MS—mass spectrometry/spectrometer
MSAG—Measurement Services Advisory Group
MSEL—Materials Science and Engineering Laboratory
MSL—Measurement and Standards Laboratories
NASA—National Aeronautics and Space Administration
NCI—National Cancer Institute
NCNR—NIST Center for Neutron Research
NCSLI—National Conference of Standards Laboratories International
NEMI—National Electronics Manufacturing Initiative
NEMS—Nanoelectromechanical Systems
NFG—nonfederal government (agencies)
NG-3—neutron guide 3
NIAP—National Information Assurance Partnership
NIF—National Ignition Facility
NIH—National Institutes of Health
NIJ—National Institute of Justice
NIR—near infrared
NIST—National Institute of Standards and Technology
NMI—national measurement institute

NMR—nuclear magnetic resonance
NOAA—National Oceanic and Atmospheric Administration
NORAMET—North American Metrology Organization
NPL—Nanoscale Physics Laboratory
NRC—National Research Council
NRIP—NIST Radiochemistry Intercomparison Program
NRL—Naval Research Laboratory
NRS—nanoscale recording system
NSA—National Security Agency
NSE—neutron spin echo
NSF—National Science Foundation
NSIC—National Storage Industry Consortium
NSMP—National Semiconductor Metrology Program
NSOM—near-field scanning optical microscopy/microscope
NTRM—NIST-Traceable Reference Material
NVLAP—National Voluntary Laboratory Accreditation Program
OA—other agencies
OAE—Office of Applied Economics
OASIS—Organization for the Advancement of Structured Information Standards
OCT—optical coherence tomography
OFA—Organizational Focus Area
OLES—Office of Law Enforcement Standards
OMP—Office of Microelectronics Programs
OOF—object-oriented finite-element (analysis system)
OOMMF—Object Oriented Micromagnetic Framework
OSEP—Optical Science and Engineering Program
OSTP—Office of Science and Technology Policy
PARCS—Primary Atomic Reference Clock in Space
PATRIOT—Providing Appropriate Tools Required to Intercept and Obstruct Terrorism
PC—personal computer
PCR—polymerase chain reaction
PDA—personal digital assistant
PDB—Protein Data Bank
PDL—polarization-dependent loss
PEEM—photoemission electron microscope
PEO—polyethylene oxide
PerMIS—Performance Metrics for Intelligent System
PGAA—prompt gamma-activation analysis
PIMM—pulsed inductive microwave magnetometer
PKI—public-key infrastructure
PL—Physics Laboratory
PLGA—polylactic/polyglycolic acid
PLIF—planar, laser-induced fluorescence
PMD—polarization mode dispersion
PRT—participating research team
QD—quantum dot

QH—quantum Hall
RCS—real-time control system; radar cross section
REML—Radio-frequency Electromagnetic-field Metrology Laboratory
RF—radio frequency
RILEM—Réunion Internationale des Laboratoires d'Essais et de recherche sur les Matériaux et les Constructions
RIMS—resonance ionization mass spectrometry/spectrometer
RNA—ribonucleic acid
RNAA—radiochemical neutron activation analysis
RPG—Recommended Practice Guide
SANS—small-angle neutron scattering
SCM—scanning capacitance microscopy/microscope
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
SFC—supercritical fluid chromatography
SFE—supercritical fluid extraction
SFG-OS—sum frequency generation optical spectroscopy
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
SM^3—Single Molecule Manipulation and Measurement
SNS—Spallation Neutron Source
SPIE—Society for Photo-Optical Instrumentation Engineers
SPINS—spin-polarized triple-axis spectrometer
SPP—storage photo-stimulable phosphor
SRD—Standard Reference Database
SRM—Standard Reference Material
SRP—Standard Reference Photometer
SS7—signaling system seven
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
SURF—Synchrotron Ultraviolet Radiation Facility
TCAD—technology computer-aided design
TDCR—Triple Double Coincidence Ratio
TDEP—trace explosives detection portal
TEM—transmission electron microscopy/microscope

TIA—Telecommunications Industries Association
TIMS—thermal ionization mass spectrometry/spectrometer
TOF—time of flight
TRC—Thermodynamics Research Center
TREC—Text Retrieval Conference
UCN—ultracold neutron
UGV—unmanned ground vehicles
UHV STM—ultrahigh-vacuum scanning tunneling microscope
ULSI—ultralarge-scale integration
UMD—University of Maryland
UpnP—Universal Plug and Play
USANS—ultrasmall-angle neutron scattering
UTC—coordinated universal time
UV—ultraviolet
UWB—ultrawideband
VCBT—Virtual Cycybernetic Building Testbed
VCCTL—Virtual Cement and Concrete Testing Laboratory
VESA—Video Electronics Standards Association
VIS—visible
VUV—vacuum ultraviolet
WDM—wavelength-division multiplexing
W3C—World Wide Web Consortium
XML—extensible markup language
XMM—x-ray multi-mirror
XPS—x-ray photoelectron spectroscopy
YBCO—yttrium-barium-copper oxide
ZSM-5—zeolite-based heterogeneous catalyst

Appendix F

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 included 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").

Robert M. Nowak (Vice Chair) is president and chief executive officer of the Michigan Molecular Institute (MMI). Before joining MMI in 1994, he retired as director of Central Research and Development and chief scientist for the Dow Chemical Company. His technical background is in the areas of organic reaction mechanisms, reinforced plastics, and new polymer synthesis and processing technologies. He is a member of the National Academy of Engineering.

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.

Ross B. Corotis is Denver Business Challenge Professor, Department of Civil, Environmental, and Architectural Engineering, at the University of Colorado at Boulder. With a background in structural mechanics and stochastic vibrations, 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.

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.

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.

Syed Z. Shariq is RGK Foundation Scholar, and leader, RGK Program on the Knowledge Economy, Stanford University, and is a visiting scholar at the Stanford Institute for Economic Policy Research. Prior to joining Stanford, he served as senior advisor for Information and Knowledge Management Technologies at the National Aeronautics and Space Administration's Ames Research Center, and he worked on issues related to technology transfer and commercialization as the director of Ames's Commercial Technology Office. Dr. Shariq's other work experience includes an assignment as associate director of the Research and Development Group at SRI International, where he developed and implemented strategies for commercialization and spin-off opportunities in advanced high-technology areas. He has also been an adviser to corporations and government agencies on a wide range of strategic business and policy decisions and their implementation and has served on the faculties of several universities, including Duke and Johns Hopkins, and has been a visiting faculty fellow at Stanford University. Dr. Shariq's current research and consulting activities are focused on the strategic management of knowledge with emphasis on the role of tacit knowledge and cognition. He is currently a senior research fellow of the University of Texas's IC2 Institute, which focuses on science and technology commercialization, and is associate editor of the *Journal of Knowledge Management*.

EX OFFICIO MEMBERS

Panel for Electronics and Electrical Engineering

Lori S. Nye (Chair) is senior director of Marketing and Sales at SiGen. In addition to her engineering experience related to semiconductor fabrication, she has extensive managerial experience and a broad perspective on trends and needs in the semiconductor industry, particularly in the areas of materials and metrology. Prior to joining SiGen, she spent many years at MEMC Electronic Materials, Inc., where she held a variety of positions, including vice president for 200-mm Product Management and vice president for Strategic Corporate Services. Before that, she was at Texas Instruments. She has a B.A. in mathematics and a B.S. in physics from Texas Women's University. She has been active in domestic and international standards activities and is serving on the program committee for the 2002 International Conference on Characterization and Metrology for ULSI Technology.

Constance J. Chang-Hasnain (Vice 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 and of the Optical Society of America and has been a Packard fellow, Sloan fellow, and National Young Investigator.

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 Cincinnati Machine, a UNOVA Company, 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 a 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

Janet S. Fender (Chair) is chief scientist of the Space Vehicles Directorate at the Air Force Research Laboratory in Albuquerque, New Mexico. She possesses technical expertise in optical sciences and space technologies. Before taking on her current job in 1997, she was technical director and scientific and technical senior scientist in the laboratory's Optical Sensing Division. She received a B.S. in physics and astronomy from the University of Oklahoma and an M.S. and Ph.D. in optical sciences from the University of Arizona. She is active in international technology issues and is a past president of the Optical Society of America. She is a fellow of the Optical Society of America and of the International Society of Optical Engineering.

Duncan T. Moore (Vice 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, N.Y., a company that manufactures 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.

Panel for Materials Science and Engineering

James Economy (Chair) is currently a professor in the Materials Science and Engineering Department at the University of Illinois at Urbana-Champaign (UIUC). He specializes in the synthesis and characterization of advanced composites thermosets and high-surface-area adsorption systems. Before joining UIUC in 1989, he spent 14 years as manager of the Polymer Science and Technology Department in the Research Division of IBM. He is a member of the National Academy of Engineering and a fellow of the

American Association for the Advancement of Science, and for many years he was a member of the U.S. National Committee for the International Union of Pure and Applied Chemistry.

David W. Johnson, Jr. (Vice Chair) retired recently from his position as the 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.

Panel for Building and Fire Research

Janet S. Baum (Chair) is a principal at Health, Education & Research Associates, Inc. She is a registered architect and construction supervisor. She specializes in the programming, planning, and design of technical facilities and research laboratories, particularly those for work in biotechnology and materials science. She has taught laboratory and biotechnology facility design courses at Harvard University and is widely published on laboratory health and safety guidelines. She has a B.S. in architecture from Washington University and a master's of architecture from Harvard.

Robert A. Altenkirch (Vice 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.

Panel for Information Technology

Tony Scott (Chair) is chief information technology officer at General Motors Corporation (GM). At GM he is responsible for defining the information technology computing and telecommunications architecture and standards across all of the company's businesses globally. In support of these goals, he works in three main areas: emerging technologies, information technology standards, and enterprise architecture. Before joining GM in 1999, he was vice president, Information Management, for the Shared Services Group at Bristol-Myers Squibb, where his responsibilities primarily included running data centers, networks, and desktop support for the company. He has also held positions as senior director, Technology Knowledge Organization, with Price Waterhouse; vice president of engineering with United Application Systems; and manager, Worldwide Information Resources, with Sun Microsystems. He has a B.S. in information systems management from the University of San Francisco and a J.D. degree from Santa Clara University.

Albert M. Erisman (Vice 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.

Panel for Measurement Services

Kenneth O. MacFadden (Chair) is vice president for Advanced Materials and Devices, Honeywell, Inc. He is currently responsible for the materials and sensors research in the Corporate Research Laboratories at Honeywell. Before taking this job in 1997, he was vice president of the Research Division at W.R. Grace & Co., where he was responsible for analytical research and for new product and process development in electrochemistry, bioproducts, catalysis, and polymer products. As director of analytical research, a position he assumed in 1984, he was responsible for corporate analytical support to the Research Division. This support included chemical and physical characterization of organic, inorganic, and biochemical materials, and compositional analysis. Other previous positions include manager, Industrial Chemicals Research, and manager, Analytical Services, at Air Products & Chemicals, Inc. In the latter unit, services provided included routine chemical and physical analysis of polymers, methods development, mass spectrometric analysis, corrosion testing, polymer characterization, and environmental methods development. He has served on the Committee of Corporation Associates of the American Chemical Society, and from 1992 to 1997 he was a member of the National Research Council panel that assesses the NIST Chemical Science and Technology Laboratory and served as vice chair (1995) and chair (1996) of that panel.